Using GIS Techniques to Determine Fire Protection Zones Considering Forest Road Network

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Abstract:
In Turkey, along the coast zone from Marmara region to east of Mediterranean region, there are forests which have been classified as first-degree fire sensitive areas. Geographic Information Systems (GIS) tools have been effectively used for many forestry activities as well as forest fire protection purposes.This study aims to determine fire protection zones in forested areas by the capabilities of GIS tools, considering forest road network. Terrestrial fire protection zones are affected by the technical capabilities of the fire-trucks, with respect to effective reaching distance of the fire-hoses from both sides of the roads. The study was applied in Forestry Enterprise Chief of Samandag located in eastern Mediterranean city of Turkey. Fire protection zones were defined according to terrain structure and ground slope classes by using GIS tools, and then, the percentage of the protected forest areas was determined. The results indicated that 73.44% of the forest areas were within the protected areas, while 26.56% of the forest was out of the reachable protected areas. It can be concluded from this research that GIS techniques can be effectively used to investigate fire protection zones based on forest road network especially in the forested areas highly sensitive to fires.

Keywords: Forest Fires, Fire Protection Zones, Forest Road Network, GIS

1 Introduction

Forest fires have been one of the most detrimental factors affecting forest resources throughout the world. Especially areas with high temperatures and lack of precipitation during the fire season are heavily affected by forest fires (Sivrikaya et al. 2011).In many Mediterranean countries (i.e. France, Greece, Italy, Portugal, Spain) including Turkey, wildfires seriously damage forests and threaten sustainability of forest resources due to their climate and other factors (Bilici 2009,Demir et al. 2009).

Turkey is one of the Mediterranean countries most affected by forest fires. In Turkey, approximately 5.5 million hectare of forest land located along the coastline starting from the eastern Mediterranean region to the Marmara region is classified as first-degree fire sensitive areas (Akay et al. 2012).In this area, about 2000 forest fires occur every year and an average of 10,000 ha forests have been destroyed every year (CFE 2008).

In Turkey, approximately 12,000 fire fighters work about 5 months long during a fire season against forest fires (Oguz et al. 2011). Fire fighting activities are performed by 5 different fire fighting crews including initial response team, reserved fighting team, mobile team, fire truck team, and aerial support team (Akay et al. 2010).Most important fire fighting crew are ground teams who are usually first to reach the forest fires by fire trucks and initiate fire fighting activities. It is very important to determine fire protection zones that can be reached by these fire fighting teams in terms of prevention and suppression of forest fires.

Advances in computer and Geographical Information Systems (GIS) have made it possible to use GIS based decision support systems in many forestry applications since it provides effective tools to collect, store, manipulate, and analyze spatial data (Sivrikaya et al. 2007,Yuksel et al. 2008,Akay et al.

2008,Gumusay and Sahin 2009, Wing et al. 2010). GIS-based decision support systems have been also usedintofire fighting planning, managing, and decision making stages (Demir et al. 2009,Akay et al. 2010, Akay et al. 2012).

In this study,it was aimed to determine fire protection zones in forested areas by the capabilities of GIS tools, considering terrain structures, ground slope, forest road network and technical capabilities of the fire-trucks. Fire protection zones are affected by effective reaching distance of the fire-hoses from both sides of the roads. The study was implemented in Forestry Enterprise Directorate of Samandag located in Forest Regional Directorate of Kahramanmaraş, Eastern Mediterranean city of Turkey. Terrain structures (downhill, uphill, flat) and ground slope classes were evaluated to determine the fire protection zones by utilizing GIS tools.

2 Material and methods

2.1 Study area

The study area covers Forestry Enterprise Chief (FEC) of Samandag located in Forest Enterprise Directorate (FED) of Hatay, an eastern Mediterranean city of Turkey(Figure 1). SamandagFEC consisted of areas sensitive to forest fires at the first degree. The study area is approximately 43265 ha with approximately 57% covered by forest lands.

2.2 GIS database

A GIS Database, consisted of various data layers (such as road network, land use classes, and slope map), was generated using ArcGIS 10 software. In order to generate these data layers, topographic maps, forest management maps, and ASTER 2010 image (15 m x 15 m) were generated and analyzed in ArcGIS 10.

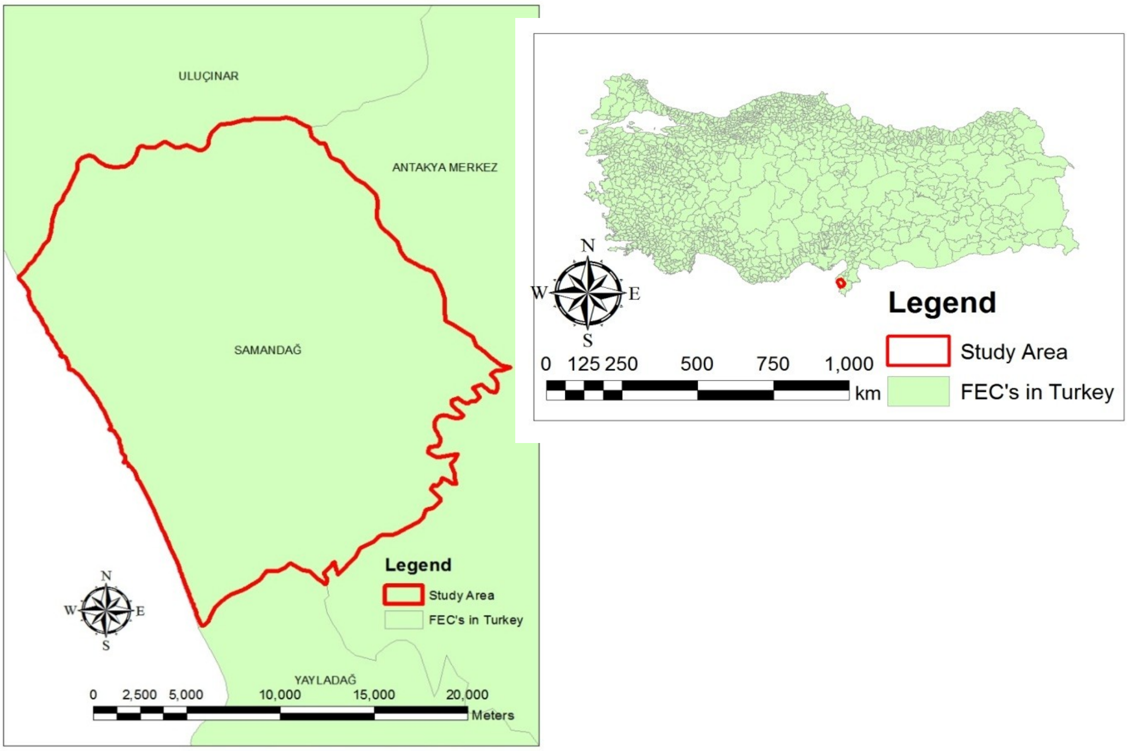


Figure 1: Study area

The road network layer was generated based on 1:25000 scaled topographic maps. 1:25000 scaled forest management map provided by FED of Hatay was used to produce the land use map of the study area. A new data layer indicating only the forest lands within the study area was also generated by reclassifying a digital version of the forest management maps. Finally, a ground slope map was produced by using ASTER based Digital Elevation Model (DEM).

2.3 Terrain structures

During fire fighting activities, fire trucks parked at the nearest road-side point to fire area spread water and chemical foams through special fire hoses. Effective usage distance of the fire hoses varies by terrain structures (uphill, downhill, flat) and ground slope. In order to determine terrain structures, a reference surface of the whole study area was generated considering surface elevations of the road network layer.

To produce reference surface, in the first stage, road network layer generated in vector format (line) was converted into raster format, then raster was converted into the point data. Also, DEM of the study area was converted into the point data. In the second stage, elevation values were assigned to each point of both road network layer and DEM by using Spatial Analyst Tools in ArcGIS 10. By using Spatial Join feature, each point of DEM was assigned by the elevation of nearest point of road network layer to generate reference surface of the study area. Therefore, attribute tableof reference surface data layer had two fieldsincluding elevation data representing reference surface and elevation of DEM.

In the third stage, a new field data representing terrain structure types was generated by subtracting the elevation values of reference surface from the elevation values of DEM by using Field Calculator feature in attribute table of reference surface data layer. The negative values under terrain structure field represent downhill areas, while the positive values represent uphill areas. If the value is zero, terrain structure is defined as flat area. Then, these values in point data format were converted into the raster format, and three raster data layers were generated for downhill, uphill, and flat areas in the study area. Finally, these terrain structures were masked out from the forest data layer to define downhill, uphill, and flat areas within the forested areas.

2.4 Fire protection zones

After defining terrain structure types, effective reaching distances of fire hoses from both sides of the road network were determined based on technical capabilities of fire trucks, terrain structures, and ground slope in order to map fire protection zones in the forested areas. Fire protection zone widths were computed for downhill (FPZ_d), uphill (FPZ_u), and flat (FPZ_f) areas as follows:

$$FPZ_d = [(P_{max} - P_{min})/(\Delta P - g)]x10 \quad (1)$$

$$FPZ_u = [(P_{max} - P_{min})/(\Delta P + g)]x10 \quad (2)$$

$$FPZ_f = [(P_{max} - P_{min})/\Delta P]x10 \quad (3)$$

where, P_{max}= Maximum water pressure at the pump, P_{min} = Minimum water pressure required for ideal water discharge from the end of the hose, ΔP = Water pressure loss at hose for each 10 m distance from the fire truck due to friction, and g = ground slope at percent.

The water pressure loss due to horizontal distance between location of fire truck and the end of fire hose changes depending on diameter of fire hoses. In this study, it was considered that 0.9 barometric unit loss occurred for each 10 m distance of fire hose with 2.5 cm diameter. Besides, the water pressures changes by 1 barometric unit depending on elevation differences between location of fire truck and the end of fire hose. For each 10 m increase in elevation (uphill), water pressure decreases by 1 unit, while it increases by 1 unit for each 10 m decreases in elevation (downhill). Since formulas above considers water pressure changes for each 10 m of fire hoses, the results are multiplied by coefficient of 10 (m) in each formula.

Fire protection zone (*FPZ*) widths were computed for three different ground slope classes (low: 0-15%; medium: 15-30%; high: 30-60%) by using the formulas and data provided above. Since it is very dangerous and inefficient to fight against forest fires at steep ground slopes, the areas with more that 60%

ground slope were not evaluated in this study. Then, net fire protection zone (*NFPZ*) widths were computed by adding the water spreading distance (distance from end of fire hose to the reaching point of water in the field) onto the FPZ widths. Water spreading distance varies by pressure of water when it comes out of fire hose. At the final stage, Buffer Analysis was performed by implementing *NFPZ* widths from both sides of road to determine the area of *NFPZ*'s considering terrain structures and slope classes.

3 Results and discussions

3.1 GIS database

The results indicated that total length of the road network in the study area was 1454 km. The largest proportion of the road network was gravel roads (51.65%), followed by forest roads (41.95%) and asphalt roads (6.40%). According to land use map of the study area, there were 10 different land use types (Figure 2). The results indicated that the largest land use type in the study area was high forest (56.84%), followed by agricultural areas (32.27%), and residential areas (8.50%). The areal distribution of the land use types were shown in Table 1. Since forest depots are also critical areas regarding with forest fires, they are merged into high forest areas. After combining the areas, it was found that total area of forest land was 24597 ha, which was about 57% of the study area.

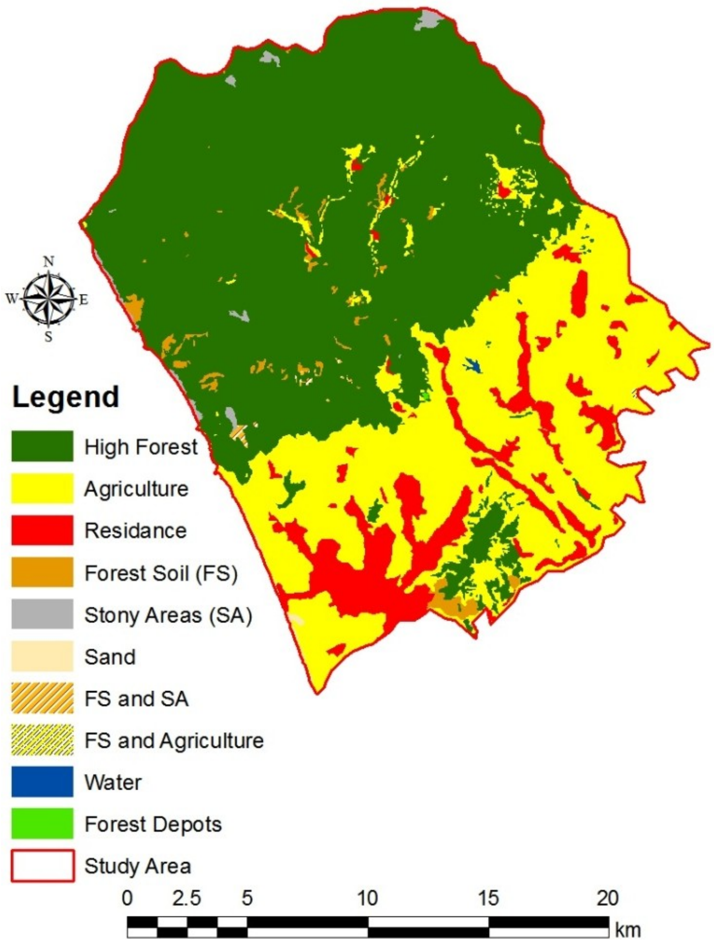


Figure 2: Land use types map of the study area

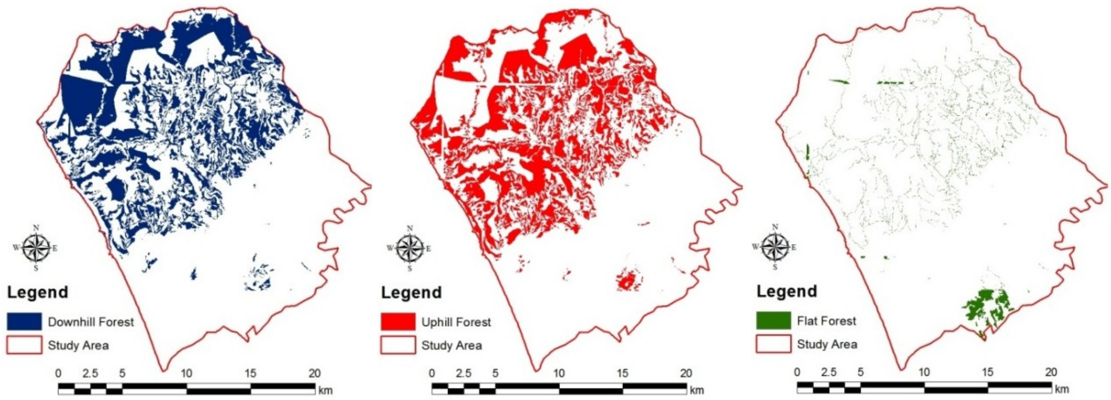
Table 1: Areal distribution of land use types in the study area

Land use types	Area (%)
High Forest	56.84
Agriculture	32.27
Residence	8.50
Forest Soil (FS)	1.25
Stony Areas (SA)	0.57
Sand	0.31
FS and SA	0.14
FS and Agriculture	0.06
Water	0.05
Forest Depots	0.01

The ground slope map was generated based on DEM of the study area. Then, slope map and forest land map was overlapped to produce slope map for forest lands. The results indicated that average elevation and ground slope was 1323 m and 9.74%, respectively. In order to determine fire protection zone widths, a new slope layer indicating three different ground slope classes (low, medium, high) were generated. The areas with more than 60% ground slope was not included into the slope classes, assuming that working on this steep ground might be dangerous and inefficient for the fire fighters. It was found that 19.88%, 35.12%, and 41.82% of the forest land was located on low, medium, and high slope areas, respectively. Rest of the area was on the steep (more than 60%) ground.

3.2 Terrain structures

The elevation values of reference surface were subtracted from elevation values of DEM to generate terrain structures. The results indicated that downhill and uphill areas in forest lands were 11725.77 ha and 11692.88 ha, respectively (Figure 3a and 3b). The flat areas in the forest land were found to be 1173.12 ha (Figure 3c). Some of the forest land could be classified under more than one terrain structures depending on the alignment of road network.



(a) (b) (c)

Figure 3: The areas of terrain structures (downhill, uphill, flat) in the forest land

3.3 Fire protection zones

Fire protection zones were determined by using fire protection zone widths which were computed for three different terrain structures by using *Equations1*, *2*, and *3*. Table 2 indicates *FPZ* and *NFPZ* widths based on terrain structures and ground slope classes. For flat areas, *FPZ* and *NFPZ* widths were computed as 378 m and 400 m, respectively.

Table 2: Fire protection zone and net fire protection zone widths with respect to terrain structures and ground slope classes

Slope Classes	Downhill		Uphill	
	FPZ	NFPZ	FPZ	NFPZ
Low	453	475	324	350
Medium	567	600	283	300
High	1133	1150	227	250

By using Buffer Analysis, fire protection zones were determined for three slope classes based on NFPZ widths. Then, they were combined by using Mosaic feature in ArcGIS 10 to findprotectedareas for each terrain structure. The results indicated that 85.51%, 60.96%, 96.85% of the downhill, uphill, and flat areas in the forest were within the protected areas, respectively.

When combining protected areas of all three terrain structures, it was found that 73.44% of the forest land was within the protected areas, while 26.56% of the forest was out of the reachable protectedareas (Figure 4). About 12% of the unprotected area was defined as unreachable due to steep ground slope (>60%). These results suggested that road density in the study area should be increased in order to reach most of the forest land during fire fighting activities.

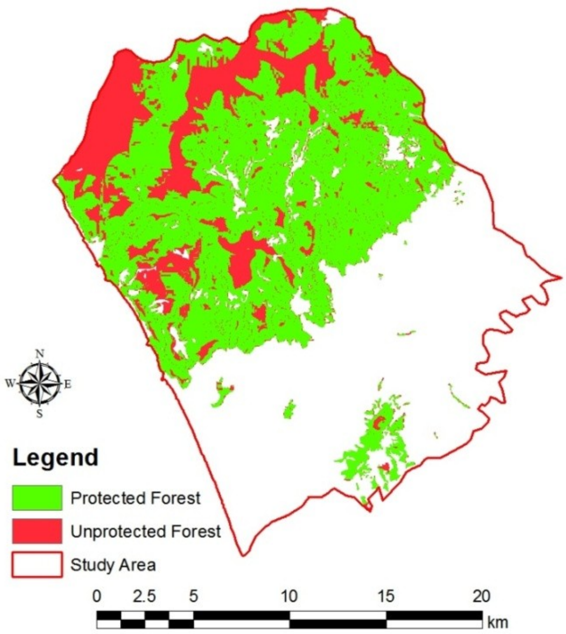


Figure 4: Protected and unprotected forest lands in the study area

4 Conclusions

This study aims to evaluate forest roads for fire protection purposes in the opening zones in terms of the prevention and suppression of forest fires. Terrestrial fire protection zones have beengeneratedby determining the effective reaching distance of the fire hoses from both sides of the roads, based on the technical capabilities of the fire trucks,terrestrial structures, and ground slope. Spatial analysis, surface analysis, and buffer analysis had been implemented by using the capabilities of GIS tools. The study area was classified into protected and non-protected zones by calculating the percentage of the protected forest areas. The results indicated that 73.44% of the forest land was within the protected areas, while 26.56% of the forest was out of the reachable protected areas. The example implemented in this study indicated that

GIS-based decision support systems can be effectively used to assist fire managers in taking necessary measures before and during the forest fires.

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