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The Vital Role of Geographic Information Systems to Fight Forest Fires

Abstract

Forest fires lead to disastrous consequences such as huge economic and ecological losses in every country. Turkey has accumulated great deal of experience in forest fires. Nevertheless, because of under-utilisation of relevant technological tools, Turkey has not been able to make adequate use of this experience. Unless fire managers be able to use relevant technological tools, however, it is unlikely to be effective and achieve desirable outcomes. The most critical issue of fire fighting is to manage it, since decision-making is extremely crucial when there is a fire. Experience of technicians makes a difference during a fire. But that would be hardly enough to give right and timely decisions. Thus, in addition to know what to do during a forest fire, it is vital for a fire fighting management to have relevant information to make fast and right decisions to reduce costs. Related decision support systems such as Geographic Information Systems (GIS) are invaluable in this respect. GIS help a fire management to give right and timely decisions not only with required paper maps and other related outputs of the area, but also with the simulation of the fire through a simulation program integrated to the system. This paper will introduce GIS with the particular focus of simulation programs they integrate and provide some samples for their applications.

Keywords: forest fire management, geographic information systems, simulation models

1. Introduction

Forest fires might lead to disastrous consequences such as huge economic and ecological losses in Turkey, Eastern Mediterranean, Balkans and adjoining regions of the Near East and Central Asia and many other regions. On the other hand, discussions have arisen on whether fire is a disaster or a natural phenomenon (Landsberg, 1997). Although public opinion and media approach fire as a disaster, forest fire researchers advocate that it is a natural occurrence that shapes function and structure of forest and other ecosystems. Researches on this subject support the idea that fire is a natural and ecosystem-regenerating phenomenon. Therefore, prescribed fire can be used in forest resource management for recycling of nutrients, regulating plant succession and wildlife habitat, maintaining biological diversity, reducing biomass, and controlling insect and disease populations (Rideout et al., 2003).

No matter what we think of either fire, whether as a natural phenomenon or a disaster, it is an emergency we must not leave unconfined. Thus it is critical to have the right data, at the right time, displayed logically in order to respond and take appropriate action in this emergency. If right data are not provided, decision will be made with inadequate information. This costs time, money, and in some cases lives (Johnson, 2000).

When fire statistics are reviewed it stands out that larger fires have little percentage in the number of fires but they constitute greater than the half of total burned areas. Actually these large fires have caused huge economic and ecological losses and aroused public interest. Either in large fires or in prescribed fires it is hard to manage fire suppression activities. This is because adequate information is needed therefore on like fuel type, fuel condition, terrain data (slope, aspect, elevation), weather data (wind, temperature, etc), other vegetation data (canopy cover, stand height, crown base height, etc), condition and position of fire fighting personnel and equipment, natural barriers, water resources of near environment, threatened settlement, establishment storing or producing dangerous material, and other information in relation to fire and see it on the map as a war commander. Otherwise, whatever experiences you have, it will be miraculous to subscribe fires by memorizing all this information in mind and making necessary management plans.

Most of the data requirements for fire fighting management are of a spatial nature and can be located on a map. Using GIS in an emergency as a decision support system bears great advantages. In other words, during the forest fire it will be easier and faster to make decision by looking at the maps and other GIS outputs of concerning fire areas or simulation model of fires in computer compared to expressing verbally. GIS provides a mechanism to centralize and visually display critical information during an emergency (Johnson, 2000).

Without ability or possibility of using GIS, forest fire management will be affected negatively in Turkey, Eastern Mediterranean, Balkans and adjoining regions of the Near East and Central Asia. In fact, use of GIS would greatly contribute to the better application of previous experience in fire management. The critical point where experiences show it is the management of a fire suppression operation. At this point if you don't have enough experiences or information making a decision you get shilly-shally and nothing to do without waiting for burn out itself. Thus whenever make a decision faster and right GIS is necessary as an emergency management system. Today GIS help to manage various emergencies such as wildfires, tsunami, floods, earthquakes, hurricanes, epidemics, chemical cloud dispersion, and oil spills, etc. (ESRI, 2000).

GIS provides fire manager with right and timely information not only with required paper maps and other related outputs of the area, but also with the simulation of the fire through a simulation program integrated to the system. This paper will introduce GIS with the particular focus on simulation programs they integrate, and will show some examples for their applications.

2. Geographical Information Systems in Forest Fire Management

A Geographic Information System (GIS) may be defined as "...a computer-based information system which attempts to capture, store, manipulate, analyze and display spatially referenced and associated tabular attribute data, for solving complex research, planning and management problems". GIS belongs to the class of computer systems that require the building of large databases before they become useful. Unlike many microcomputer applications where a user can begin use after the purchase of the hardware and software, the use of a GIS requires that large spatial databases be created, appropriate hardware and software be purchased, applications be developed, and all components be installed, integrated and tested before users can begin to use the GIS. These tasks are large and complex, so large in fact, as to require substantial planning before any data, hardware or software is acquired (Becker et.al., 1996).

Over the past decade the geoinformatic field has evolved from a highly specialized niche to a technology with broad impact on society and its interaction with nature. Geographic Information Systems (GIS) applications now range from simple navigation to critical and extremely complex tasks, such as prediction and management of natural disasters. Due to the increased use of GPS, faster access to geo-referenced data, expanding field of remote sensing and real-time monitoring, GIS technology is entering many new disciplines and industries and GIS is becoming a part of general computational infrastructure. It is therefore natural that geospatial tools are being developed also within the Open Source and Free Software community (Mitosava and Neteler, 2002).

Thanks to developments of telecommunication and computer area it is possible to store large amount of data in mobile computer and transfer data from main database by wireless communication. Thus mobile or non-mobile fire management headquarter can be established during the forest fire.

The software components of geoinformation technology have a profound impact on the capabilities to effectively use the spatial data for solving a particular problem. To ensure continuous innovation and improvement, existence of diverse approaches to GIS software development is crucial. Besides the widely used proprietary systems, an Open Source and Free Software GIS plays an important role in adaptation of GIS technology by stimulating new experimental approaches and by providing access to GIS for the users who cannot or do not want to use proprietary products (Mitchell et al., 2002). GRASS (Geographic Resources Analysis Support System) is one of the most widely used GIS software especially in natural resources, and it has developed under GNU General Public License. Some modelling modules (erosion modelling, rainfall-runoff modelling, storm water runoff, hydrologic modelling, watershed calculation, floodplain analysis, landscape analysis, wildfire spread simulation) of GRASS offers great challenges. Data transfer from known GIS software has been solved. It has got both raster and vector GIS capabilities, image processing and other graphics functionality.

The applications of the GIS are increased and detailed parallel to software and hardware developments. GIS has become an important tool in various branches of forestry. One of the applications of GIS in forestry is forest fire. Forest fire applications of GIS, can be classified in three main categories:

- Establishment of real-time fire risk and hazards database,
- Analysis of database for making decision during the forest fire,
- For better prediction of forest fire behaviour, making simulations by simulation software integrated to GIS software or self executed.

Second and third categories of above will be focused on in this paper. A good example study of first category has been completed by Southwest Anatolia Forest Research Institute of Turkey.

Existing main database must contain fire data useful for GIS in fire management headquarter established during the fire. If this data is available, desired information (for example: elevation, slope, aspect, fuel model, canopy cover, canopy height, canopy base height, fuel moisture, roads, water resources, etc.) will be acquired rapidly by queries and analysis of main database (Figure 1). Beside two-dimensional spatial outputs, this information can be seen on the digital elevation model of the same area.

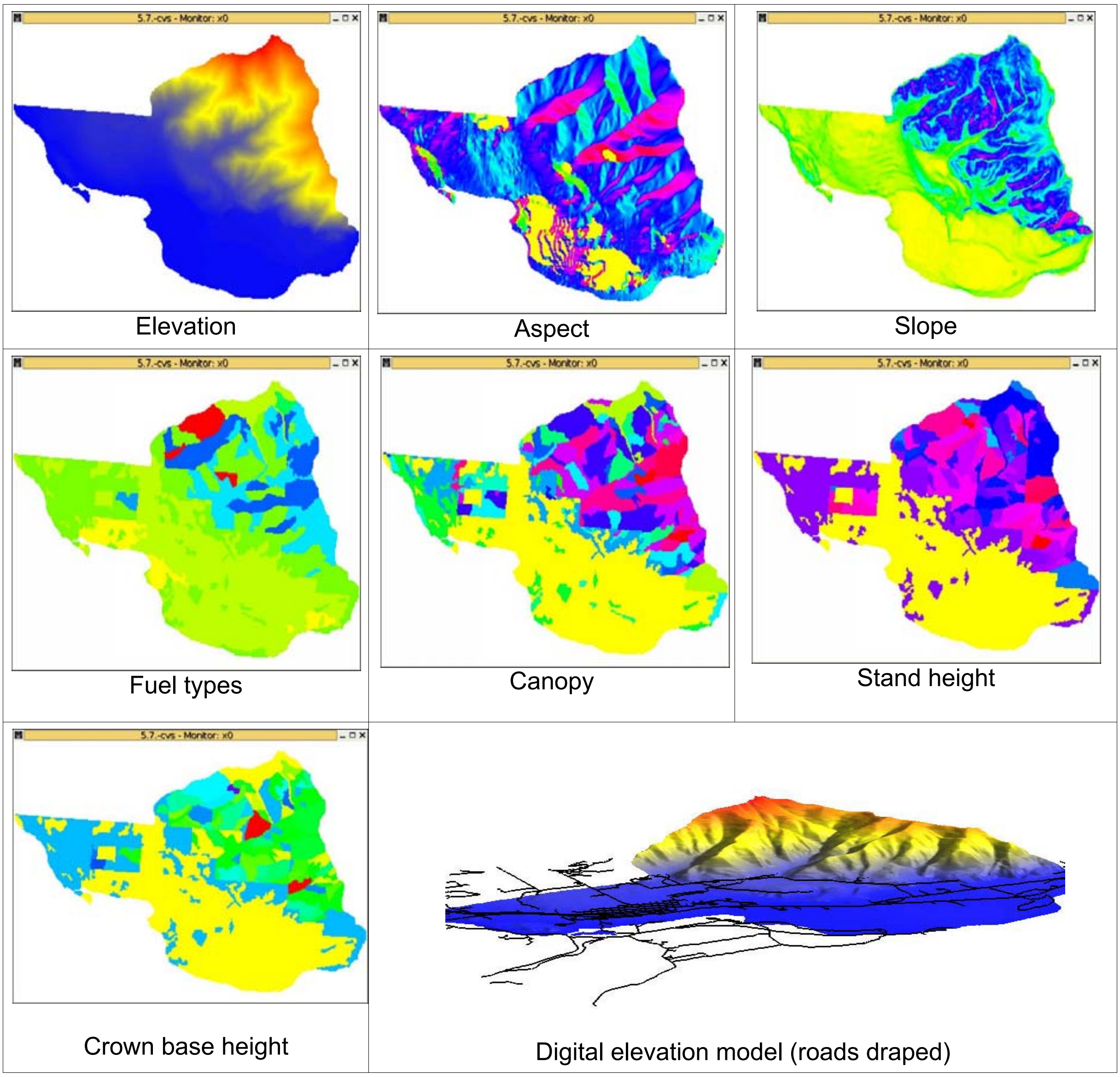

Figure 1. Some fire related GIS layers

3. Forest Fire Simulation Models

Resource management requires increasingly more effective fire management. Fire managers require ways of evaluating the various elements affecting ignition potential and probable fire behaviour for proper fire control and use. Fuel, weather and topography are the main factors that affect fire behaviour (Hawkes et.al., 1995).

FIRE ENVIRONMENT

Pre-fire conditions

- Fuel type, description
- Fuel condition, moisture content
- Weather --wind, temperature, etc.
- Terrain--slope, elevation, aspect

FIRE CHARACTERISTICS

Processes that take place during the fire

- Ignition
- Extinction
- Fire state -- flaming or smouldering
- Flame dimensions -- length, height, depth
- Intensity
- Rate of fire spread
- Fuel consumption
- Emissions -- gaseous and particulate
- Heat transfer above the surface
- Heat transfer below the surface

FIRST ORDER FIRE EFFECTS

Prompt and local--measurable within a few days after the fire and restricted almost totally to the burned area

- Reduction in fuel loading
- Exposure of mineral soil
- Mortality or thermal injury to vegetation
- Chemical and physical response of fire-heated soil
- Local air quality

SECONDARY FIRE EFFECTS

Removed from the fire area and/or resulting after a longer time delay

- Erosion
- Smoke transport and dispersion
- Health effects due to air quality
- Wildlife habitat change
- Water quality change
- Economic impact
- Visual change of the landscape
- Global climate change

Figure 2. Fire modelling is categorized as fire environment, fire characteristics, first-order fire effects, and secondary fire effects. Examples are given for each category (Andrews and Queen, 2001).

Although these factors can be seen directly on the output of GIS as a GIS levels, it is better to see their modelling in the simulation software environment for predicting fire behaviour perfectly. Some of this simulation software is working in integration with GIS software, and the others work as a self-executables. This software helps managers to make fast and reliable decision during wildland fire or prescribed fire. Simulation software has different functions and models. These models can be categorized by various points of view but classification suggested from Andrews and Queen is rather meaningful (Andrews and Queen, 2001) (Figure 2).

Fire environment models describe the conditions that can be defined before a fire event. The results are used in fire characteristics models, which are in turn used by first order effects models. Those immediate and local effects plus many other influencing factors are then used to calculate secondary effects.

Simulation software is used widely in the USA and Canada, and developed continuously. To highlighting the subject a simple example of wildfire simulation was realized through wildfire simulation modules (r.ros, r.spread, r.spreadpath) of GRASS Open Source GIS Software. In these modules, developed by Jianping Xu and Lathrop (1995), Rothermel's wildfire mathematical model has been used. Because of open source code of modules, making any desired changes are possible.

Since it was not possible to obtain relevant data, a sample data of FARSITE simulation program has been processed by GRASS, after it was transformed into an appropriate format. To render this transfer “.shp” files imported by “v.in.ogr” command and “.asc” files imported by “r.in.ascii” command. Because fuel moisture (live fuel moisture, 1 hour moisture, 10 hour moisture, 100 hour moisture) and weather data (wind speed, wind direction) read from raster map in GRASS, FARSITE text data were converted into separate raster maps by “r.reclass” command. After data transferring has been completed first they were entered “r.ros” wildfire module and produced four maps (base rate of spread, the maximum rate of spread, the direction of the maximum rate of spread, the maximum potential of spotting distance) to use in “r.spread” module.

Then these raster maps and other data were processed in “r.spread” to simulate forest fire desired location and duration (Figures 3, 4).

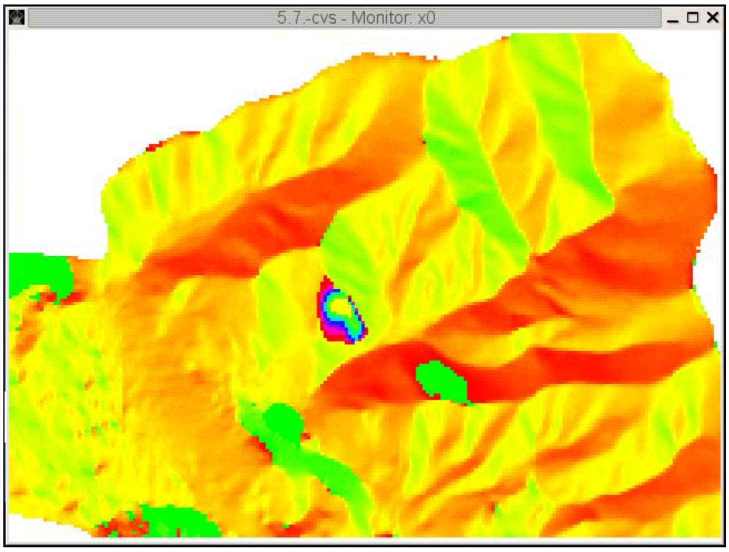

Figure 3. Simulation results overlayed aspect map

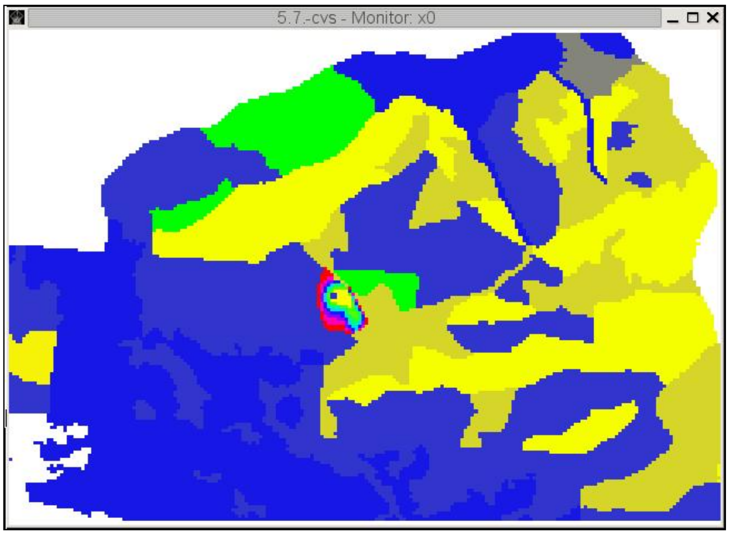

Figure 4. Simulation results overlayed fuel map

4. Conclusions

A new era has been started with the advent of GIS in management of natural resources and urban environment. Developments not only in GIS and related disciplines but also in computer and telecommunication areas have improved the acquirement, storage, and communication of data. These developments have led to rapid increase in GIS applications and development of GIS software in various areas of applications. One of such areas is forestry. Of course, GIS has branched into many areas in forestry (for example: watershed applications, silvicultural applications, forest inventory and management applications, forest fire applications, etc.). Either natural phenomenon in regeneration of ecosystems or a disaster causing economic and ecological losses, forest fire is an emergency to be dealt with carefully and systematically. In such a situation forest fire managers need information about elements affecting fire. Some of this information is spatial and obtainable through GIS. In addition to this information, fire behaviour is predicted by simulation software to help fire managers make better decisions.

In order to utilise GIS economically and productively for fire emergency management in Turkey, Eastern Mediterranean, Balkans and adjoining Regions of the Near East and Central Asia, the following criteria are taken into consideration:

- Existing geographic database must be used (development of database only for fire management would be insufficient and redundant)
- If there is not any existing geographic database, the need of forest fire information must be considered in database planning and design
- Fuel related data (fuel loading, fuel moisture, etc) that is crucial element of fire behaviour should be updated frequently
- Database has to incorporate the criteria (attributes) for fuel type classification
- Telecommunication infrastructure that enables data transfer from main geographic database must be constructed
- Existing or new simulation software should be tested in forest fires.

As a result, although GIS has vital role in fire management activities as a state-of-the-art decision support system, the most important component is the staff with the experience and expertise in forest fires and GIS.

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