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Full Length Research Paper

GIS based fire analysis and production of fire-risk maps: The Trabzon experience

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Globally, fire causes considerable losses that can be alleviated by taking appropriate precautions facilitated by sophisticated systems supported by information technologies. To eliminate or reduce the destructive effects of fires, fire risk management is a vital element for those who make the decisions (e.g. local governments and municipalities) concerning fire. For this purpose, geographical information systems (GIS) through effective spatial data storage and query can produce dynamic fire maps. In this study, the city center of Trabzon in Turkey was selected as the pilot area for the establishment of a sample fire database based on GIS and as the basis of sample spatial queries in support of fire management. For this pilot application, firstly, the fire records of the city center between the years 2005 to 2008 were examined and analyzed. Secondly, related fire data were imported into a computer environment as a GIS supported database. Later, the data in the database was visualized, analyzed and queried in order to demonstrate the capabilities of the system. Specifically, an analysis of fire hydrant location was carried out, and the related needs were analyzed. Additionally, spatial queries were performed and pixel-based risk maps were produced.

Key words: Trabzon, geographic information systems, urban fires, spatial database.

INTRODUCTION

Information technologies (IT) that have developed rapidly in recent years are also used in fire management. Parallel to the development of geographic information systems (GIS), it is possible to achieve efficient results in applications based on spatial information. Since GIS can analyze intensive data volumes and is highly effective in responding to spatial queries that can be used in the analysis data concerning urban fires. When the cost benefit analysis of the establishment of GIS is compared with economic losses that occurred as a result of fire, it can be seen that the creation and management of a system based on GIS is relatively economic.

In practice, the formation of risk maps for urban areas is not common. Similarly, in the literature, the studies based on GIS supported fire analysis are very limited although there are several empirical models (Itoigawa et al., 1989), represented by the model proposed by Zhao (2010). However, these models focus mainly on simulating the overall behaviors of urban fire (e.g. spreading speed of fire, size of the burned out area) and the physical aspects of an urban fire that spread from one building to another (Himoto and Tanaka, 2003).

Urban fire is one of the most important problems not only for developing countries but also for developed countries. On average in the United States in 2006, one person died in a fire accident approximately every 162 min and one person was injured every 32 min (Karter and Stein, 2008). The threat of urban fire is a significant problem in the United States, with building fires being responsible for over 3,000 deaths, 15,000 injuries and $9.2 billion in fire-related property damage in 2005 (Yamashita, 2000). Each year, fire cause about 300,000 deaths globally and most of these occur in the home (Zhang et al., 2006). This situation is no different for Turkey, in 2002, there were 42,367 cases of fire and the figure reached 93,601, in 2008, the loss of lives rose from 224 to 402 in that period (Table 1). In 2007, the total value of goods damaged due to fire was around 350 million dollars (GDCD, 2009).

In Turkey the Fire Brigade operated under the local municipal administration. Fire records are written on printed materials, for example the notification form before the fire and the report issued after the fire. Exceptionally, some municipalities also record this information in

Table 1. Number of urban fires and deaths in the year 2002 to 2008 in Turkey (GDCD, 2009).

Year	Number	Increase (%)	Deaths
2002	42.367	-	224
2003	56.482	33.3	505
2004	60.801	7.6	330
2005	57.293	-5.8	290
2006	81.149	41.6	349
2007	94.353	16.3	358
2008	93.601	0.0	402
Total	443.679	220	2234

databases and these are shared with other institutions in a common database. One of the main problems in the records is the determination of the location of the fire accurately. The general directorate of civil defense collects the fire records and published them annually. However, this information is generally not supported with a fire risk map indicating the locations of urban fires.

For effective fire management, conventional fire records must be supported with maps and there should be dynamic integral spatial data such as, the location of hydrants access routes together with limitations and information on risk areas. For effective firefighting it is of crucial importance that there are sufficient fire hydrants and they are appropriately maintained. In the fire reports there is evidence of shortages and nonfunctioning hydrants and this has serious implications for the successful extinguishing of the fire. In urban areas especially in old settlements, many of the streets are narrow and can prevent the entry of fire trucks and first aid teams. Furthermore, the close proximity of buildings results in the rapid spread of fire. In many urban areas in Turkey there are old wooden houses and dilapidated unoccupied properties and these can be more seriously damaged than other buildings.

In order to effectively fight against fires and to potentially prevent fire a large amount of data needs to be collected. This should include: a full description and location of the properties in the area, occupants of the buildings with special attention to the children, the elderly, physically and mentally disabled, location of hydrants and other water sources and any sources of risk in the district or area. This data needs to be in a common database and GIS can play a significant role in the accumulation and maintenance of information. In preparation for fire management, GIS can help to determine the optimum distribution of hydrants, location of fire stations, classification of fire regions according to fire type and the creation of region specific early intervention plans.

MATERIALS AND METHODS

The city center of Trabzon in Turkey (Figure 1) was selected as the study area and the records pertaining to fire fighting and prevention held by the administration of Trabzon municipality were the main data source for this study. In the urban information system that was previously created through a joint project undertaken by Karadeniz technical University and Trabzon municipality, the fire records were added to a spatial database. With this study, in the first stage, through a specially developed interface all the existing paper records from 2000 to 2008 from the fire directorate records were transferred to the database. This information include: fire type, number of dead/casualties and time taken to access the fire. In the second stage, fire address records were matched with the addresses in database. As can be seen in (Table 2), the number of fires has increased since 2002, although, the number of deaths was only 2 over the whole period and the number of people injured has increased.

From the building, fire records in Trabzon province between the years 2002 to 2008 the incidents were classified according to the basic cause of the fire. The number of cases and their causes were as follows: 641 – solid fuel cookers and stoves, 537 – chimneys, 224 – electricity, 80 – liquefied petroleum Gas (LPG), 40 – central heating, 6 – fuel oil, 3 – chemicals and 1 – gas compression.

Fire risk analysis with GIS techniques

The risk of fire in urban areas has increased over the years and the rising cost of fire losses would seem to indicate that they are increasing at a greater rate than the measure devised to control them. Cities grow in size and complexity day by day therefore they need to be managed more efficiently (Thapar, 2000). Although there are many formal definitions of GIS, for practical purposes GIS can be defined as a computer-based system to aid in the collection, maintenance, storage, analysis, output and distribution of spatial data information (Bolstad, 2005). GIS is an important and efficient tool that can be used by local administrations to minimize natural disasters. Thus, GIS technologies have been used in fire analysis related to the optimum location of fire stations, for example, Habibi et al. (2008), has made spatial analysis of urban fire stations in Tehran, using an analytical hierarchy process and GIS. The authors stated that, using models and software in urban planning has become prevalent in response to the complex dimension of the urban issues and the role of many different indicators in this field. Yang et al. (2004) also carried studies concerning the selection of fire station locations using GIS. Jasso et al. (2009) have stated that location information of fires from 911 emergency calls could not be determined accurately (Jasso et al., 2009). GIS by matching address information with coordinate information directly helps in the determination of places of fires or accidents in the shortest time. The literature reveals an increasing use of GIS in the fire service in the last decade (Corcoran et al., 2007).

The Importance of fire information system (FIS) in urban areas

Unlike a flat paper map, a GIS-generated map can represent many layers of different information. This representation provides a unique way of thinking about geographic space. By linking map databases, GIS enables users to visualize, manipulate, analyze and display spatial data. GIS technology can create cost-effect and accurate solutions in an expanding range of applications. GIS displays geographic data as spatial data layers. The data layers used in this study in the design of GIS for fire are given in (Figure 2).These data layers and their attribute data can be expanded according to needs analyses and user requests. These needs analyses should include queries and the requirements for effective fire fighting before, during and after the fire (Table 3).

The fire information system (FIS) should be connected to the GIS database so that when needed, any query can be acted upon to

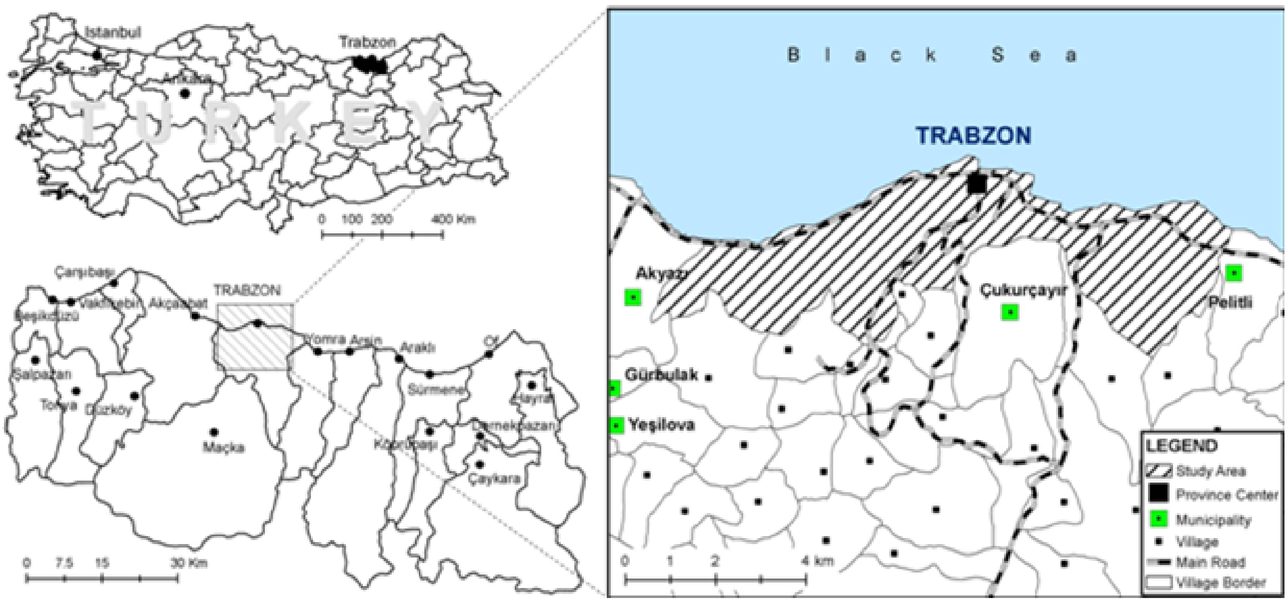

Figure 1. Study area.

Table 2. Number of fires in Trabzon City Center from 2002 to 2008.

Year	Number of fires	Increase on previous year (%)	Deaths	Injuries
2002	151	-		2
2003	159	5.2		3
2004	227	42.8	1	3
2005	256	12.8		7
2006	233	-9.0		8
2007	241	3.4	1	6
2008	265	10.0		7
Total	1532	75.5	2	36

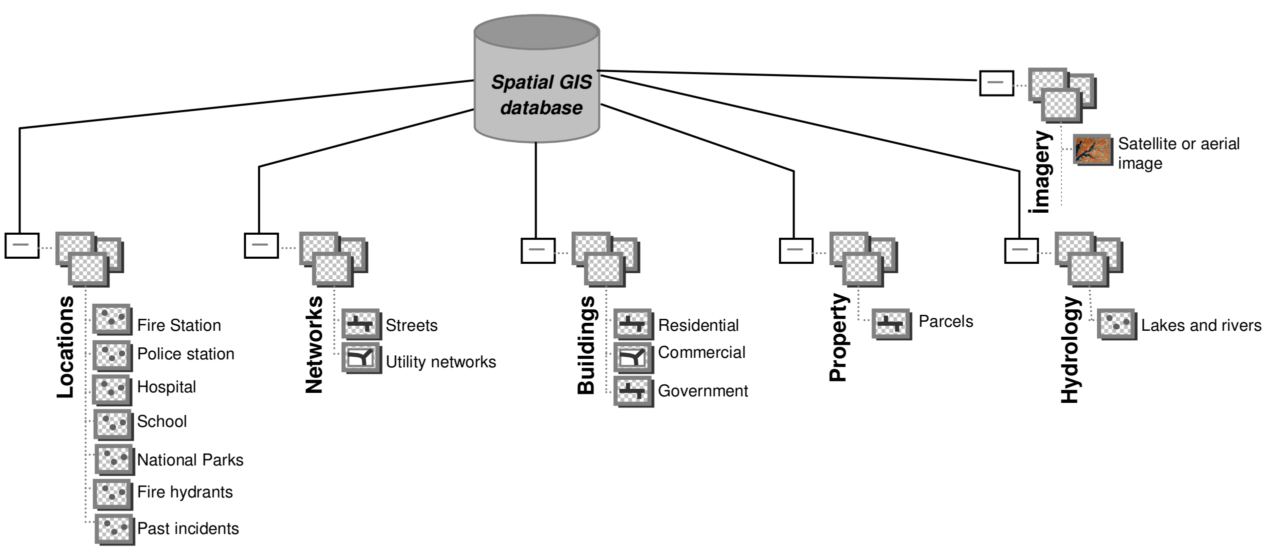

Figure 2. Main spatial data layers used in GIS related to fire incidents.

Table 3. Fire information system needs analysis.

Before	At the incident place	Before and after fire
Location and spatial distribution of hydrants and maintenance status	Where is the nearest hydrant?	Check on maintenance status
Are fire stations located appropriately?		Are fire stations located appropriately?
Areas that cannot be accessed by fire trucks and other emergency vehicles.		Areas that cannot be accessed by fire trucks and other emergency vehicles.
Road information		Update Road information.
Where are tall buildings requiring special fire fighting techniques?	Where fire building exits?	
Building danger classification (high, medium and little danger)	Are there available building plans? (architecture, machine, etc)	Revise building danger classification
Building address and database	Are there people living in house? (children, elderly, disabled etc)	Update database information
	Location of the nearest first aid centre? (hospital, health center)	
Where are the water depots and other water resources in urban environment?	Where is the nearest water source?	Revise information on water depots and other water resources and their current condition.
Analysis of fire risk regions		
Where are areas that have a risk of explosion (petroleum stations, transformers)?		Update information about areas that have a risk of explosion
Fire database to be maintained (Type, date, time, dead-casualty, economic damage, etc)		Fire database to be updated

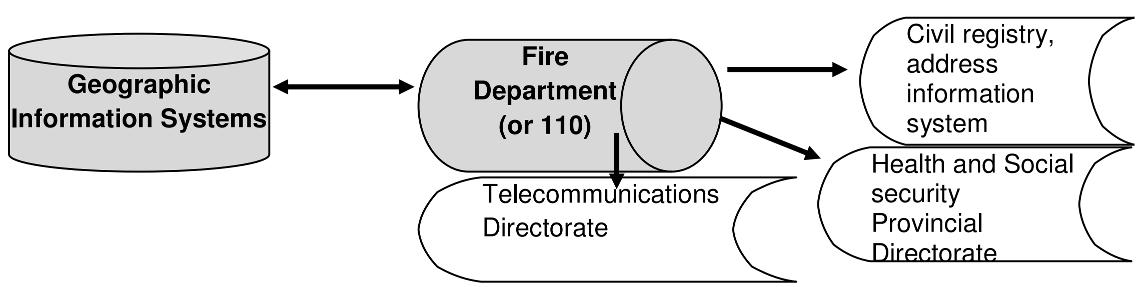

Figure 3. Basic structure of distributed data model for FIS.

receive the required information from the GIS database. For example, a request for information about the inhabitants living in the building that is on fire can be obtained immediately. The number of elderly people who have died in fire in many countries is not to be overestimated. By gaining information about the number of residents and their physical or mental condition by accessing social health database, (Figure 3) can save many lives. Additional information on the residents should be obtained from the civil registry, social health organizations and amalgamated into the FIS database. Furthermore, the FIS should be able to access information in GIS database at the moment of the fire about the building (architectural detail including fire escapes, building static, the location of gas and electricity supplies). In this way, fire teams will be able to act quickly and effectively and more importantly, with greater safety when dealing with a fire. In addition, the address of the building on fire or the address of the reporter should be acquired by integrating GIS database for fire management with the database of the telecommunications directorate and civil registry as shown in (Figure 3). In this way, through this distributed data model the FIS will be optimized and work more works efficiently.

In order to maximize the fire fighting ability of the fire brigade and thus saving live, preventing injury and reducing the economic losses incurred the fire directorate should ensure that the records are regularly updated and undertake such studies as necessary to maintain an accurate database that can be shared with relevant parties.

GIS is a complement of systems which can produce solutions in finding answer to questions such as how to prepare for fires in areas where fire truck access is restricted (or prevented), where there is a need for more fire hydrants and whether maintenance is required in existing hydrants, is the current distribution of fire stations adequate and are they appropriately located and where are the areas of particular risk. This paper describes the development of the FIS model for Trabzon city using GIS technology and shows how appropriate databases are to be created to respond to queries and provide information for analysis.

CASE STUDY AND RESULTS

In Turkey, access roads to buildings for fire trucks are

Figure 4. Sample for streets that a fire truck cannot enter (Cömlekci district, Ortanca and Cemiyet Street).

Figure 5. Example of the lack of visibility of some hydrants covered by plan.

defined in article 22 of the regulation on protection of buildings from fire. According to this, “inner access roads are the road providing access to a building from a main road. The normal width of inner access roads must be at least 4 m and in the case of a dead end street, it must be 8 m.” Based on this article of the regulation and the width of a fire truck being 3 m the roads that cannot be entered were determined using road and building data from the database. For this analysis, buffer areas of 2 m around each building were created in the database as a buffer layer. Then, the road data was intersected with the buffer layer formed and finally, roads were determined where a fire truck cannot enter or where there is insufficient space to maneuver (Figure 4).

Spatial distribution analysis of hydrants

An important layer of a FIS is placement of hydrants. In the study area, total number and location of hydrants were not known. Therefore in this study, using the Topcon GMS 2 DPGS device that can make measurement below meter accuracy and that operates on a double satellite system (GPS-GLONASS), the locations of known hydrants was found and transferred to spatial database. It was also detected in the study that some hydrants are surrounded by plants (Figure 5) thus, they are not visible at night. In addition to the work on hydrants, the locations of water mains and depots within the topological structure were recorded in database.

In clause 3 and 11 of article 95 of the regulation on protection of buildings from fire that “hydrants to be placed within system to cover the immediate and nearby buildings and for fires not extinguished in the first intervention fire trucks should be able to gain access easily and use the hydrants to protect other buildings from the fire. The distance between hydrants is taken 50 m in very high risk regions, 100 m in high risk regions, 125 m in medium risk regions and 150 m in low risk regions.”

Since after the fire intensity analysis produced as part of the study the Kermekaya district of Trabzon city was determined to be in very high risk category, it is concluded that the existing 4 hydrants are insufficient and the distance between these fire taps is far higher than the required distance for high risk fire regions as stated in the regulations. Therefore, it is determined that in the Kemerkaya district, 50 additional hydrants are required, the locations of the existing and proposed hydrants are shown in (Figure 6).

Analysis of accessibility to fire in shortest time

Access to a fire incident and making an intervention in the shortest time has the great importance for extinguishing a fire. In this analysis, the areas that fire truck can reach according to certain time intervals and speed were determined. The speed of fire truck used in the analysis, its access time to the incident site was obtained from previous records in the fire database and the distance of fire site to the fire station were examined. The areas to be accessed in 5 min were determined using a truck traveling at 45 km/h (Figure 7). The speed of the fire vehicle was calculated as an average value from the access time of the fires that occurred in previous years. It was discovered that in particular, the east of the city has the most serious risk in terms of the lack of rapid accessibility to the fire location.

Determination of high risk areas

Article 17 of the regulation on the protection of buildings from fire evaluates high risk sites at the following places:
a) Where flammable and detonable gases are stored, where the transport loading and unloading sales operations of LPG, natural gas and similar gases are

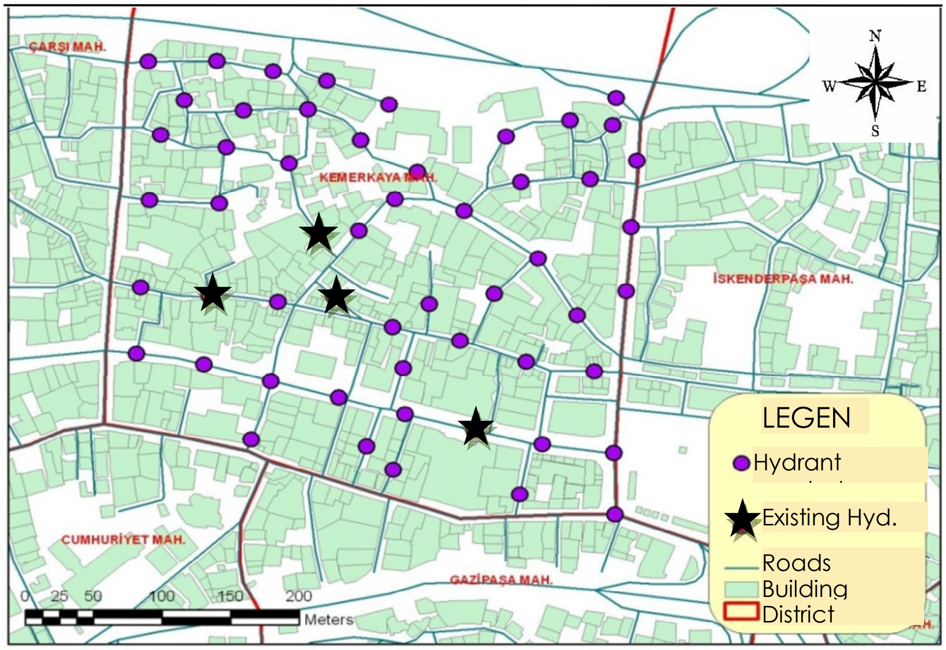

Figure 6. Spatial distribution of fire hydrants the Kemerkaya district in Trabzon City.

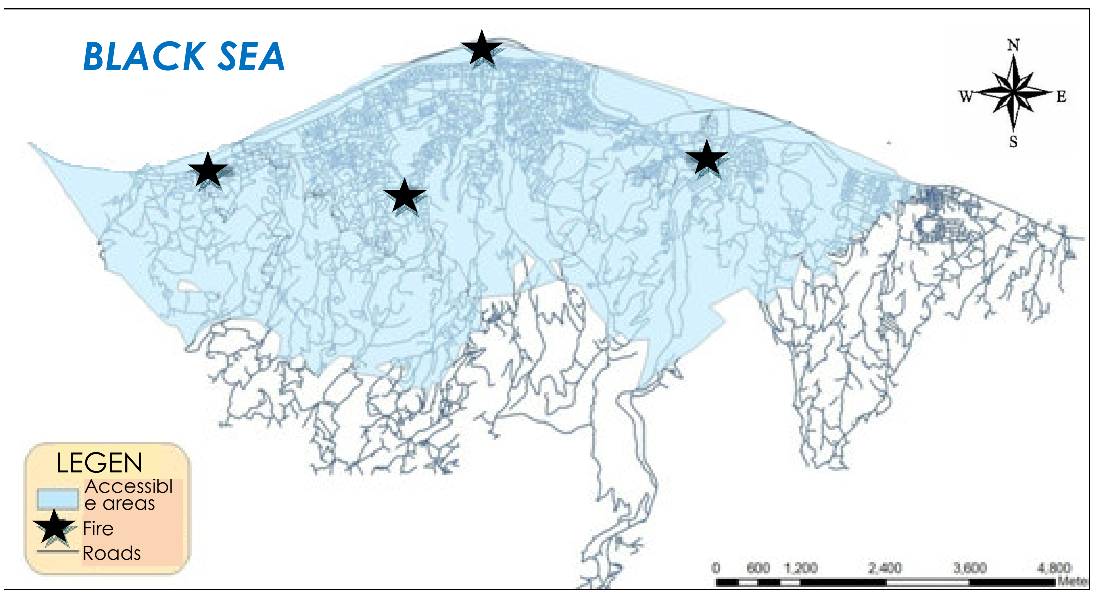

Figure 7. The areas that a fire truck can access within 5 min in Trabzon city.

carried out.
b) Where flammable materials that can explode easily with the effect of heat and pressure are found, where munitions, gunpowder, dynamite and similar materials are produced, stored and sold.
c) Where inflammable liquids are produced, stored and sold. In consideration of these criteria, together with the analyses and queries that were conducted, 99 high risk areas in Trabzon were determined in accordance with the regulatory information given above. The distribution of these sites is shown in (Figure 8).

Determination of fire density

Fire density is determined according to the numbers of

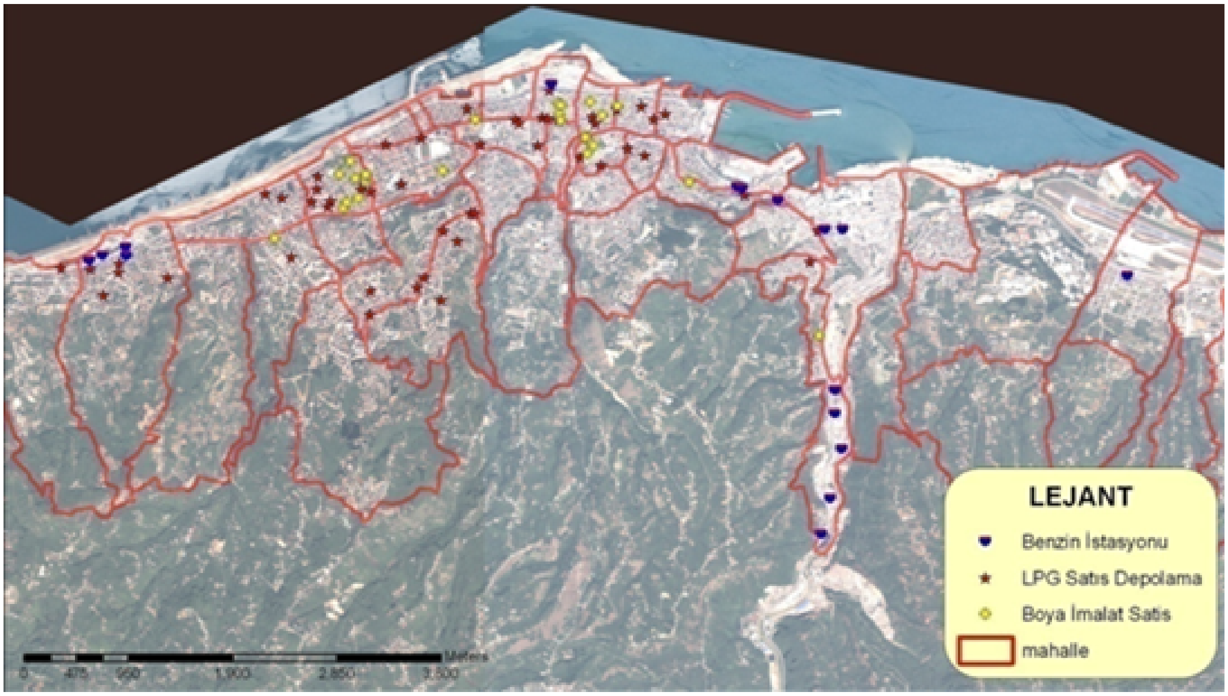

Figure 8. High risk places found in and around Trabzon city center.

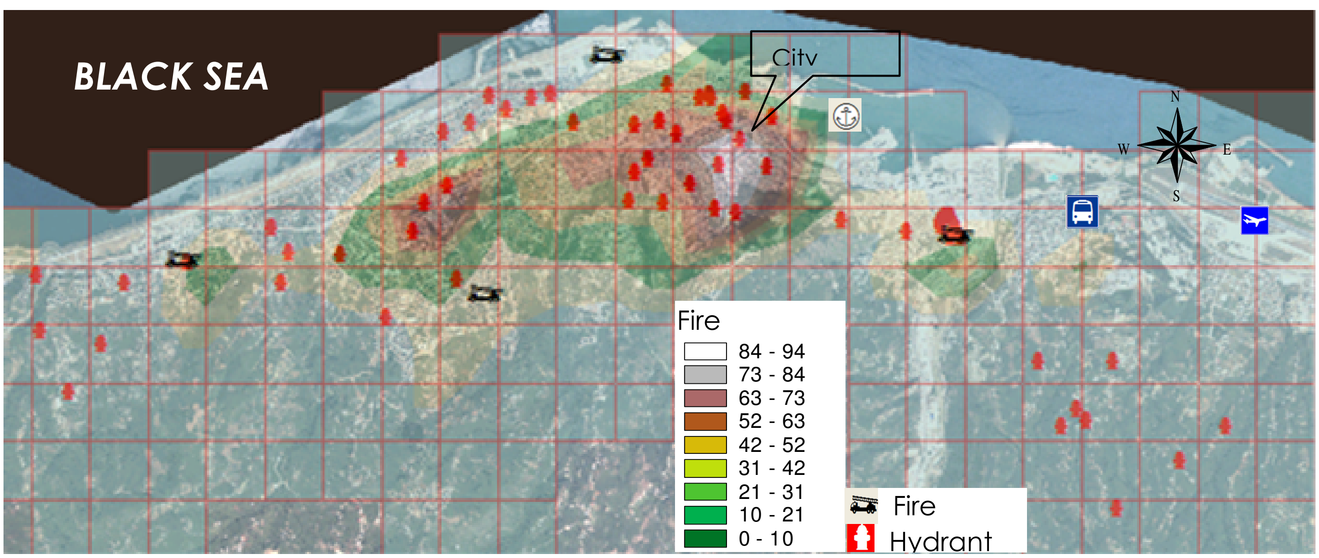

Figure 9. Fire density risk map of Trabzon city and vicinity.

fires that occurred in a given period of time. The required data for this was obtained from the database created for Trabzon city. For this analysis, first, a grid network of 500 by 500 m formed to cover all the city was overlaid with the quick bird satellite image of the city (Figure 9). Then this network is transformed into ArcGIS topological data, fire density of each pixel was detected according to the number of fires within each pixel. This process provides a visible display of the fire density in the city. When fire density map was examined, a total of 369 fires were seen to be concentrated on the city centre with the density decreasing from the city center outwards (Figure 9). In other words, there is inverse proportion between the distance to the city center and number of fires and the density. The reason for this distribution arises from the city center being an old settlement, with old buildings and the heating being provided by coal or gas burning stoves.

Conclusion

In this study, the fires that occur in Trabzon city were recorded according to numbering system and on street basis in a GIS database. In addition, it is now possible to facilitate a more developed analysis by associating the fire site database with the building and cadastral parcel database. The data comprising graphical database within the FIS pilot application for Trabzon city consists of spatial data such as fire station and hydrant location, roads, satellite images with high resolution, written and verbal details relating to buildings (such as residential, official facilities, factories, depots). It was found that the spatial information of hydrants is deficient and the current data on their usability is not available. It was also observed that there were administrative problems in terms of the purchase, maintenance and repair of hydrants. Furthermore, the distribution of hydrants is not compatible with the regulations, there are insufficient numbers of hydrants in the areas where fires are considered to be intensive. There are errors in the existing records of fire reports, such as address, fire occurrence and access time to the fire, however, these errors can be reduced to a minimum using the prepared interface. Furthermore, it has also been observed that a standard for spatial and attribute data with respect to fire records has not been developed. It has been seen after the GIS analyses that there are many problems that will continue to be experienced in the access to many streets and it is important that more hydrants are installed in these areas to allow effective fire fighting. It has been monitored that the measures required, has not been taken in the intensive fire areas found at the end of GIS analysis although it is evident from fire records that the intensity of fires in these regions are high.

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