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Fire Analysis and Production of Fire Risk Maps: The Trabzon Experience

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1. Introduction

Today fire has an important place among the causes of loss of life and property. To intervene as soon as possible is of great importance, to eliminate or reduce the destructive effects of fires. Effectiveness of the intervention is directly linked with instant access to the fire, but the topography of the Black Sea region makes it difficult to intervene in fires on time due to poor access. Therefore, in order to fulfill the needs of the fire service and get fires under control, systems supported by information technologies can be used.

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 analyse intensive data volumes and is highly effective in responding to spatial queries, it can be used in the analysis of data concerning urban fires. When the cost-benefit results of GIS are compared with economic losses that occurred as a result of fire, it can be argued that GIS provides a relatively economic solution. In practice, the formation of fire analysis 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 behaviours 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 an important problem, not only for developing countries, but also for developed countries. In the United States in 2006, one person died in a fire accident approximately every 162 minutes on average, and one person was injured every 32 minutes (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 causes 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 (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**

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

In Turkey the Fire Brigade operates 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. Sometimes, some municipalities also record this information in databases and these are shared with other institutions in a common database. One of the main problems showing in the records is the accurate determination of the fire's location. The General Directorate of Civil Defense collects the fire records and publishes 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 hydrant 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 a shortage of hydrants in addition to non-functioning hydrants and this has serious implications for the successful extinguishing of fires. In urban areas, especially in old settlements, many of the streets are narrow which 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 fires and potentially prevent fires, a large amount of data needs to be collected. This should include: 1) a full description and location of the properties in the area, 2) occupants of the buildings with special attention to the children, the elderly, physically and mentally disabled, 3) location of hydrants and other water sources and 4) 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 best distribution of hydrants, location of fire stations, classification of fire regions according to fire type and the creation of region specific early intervention plans (Nisanci, 2010).

Significantly, to eliminate or reduce the destructive effects of fires, fire risk management is a vital element for those who make decisions (e.g. local governments and municipalities) concerning fire. For this purpose, GIS - through effective spatial data storage and query - can produce dynamic fire maps. In the study presented in this chapter, the city centre 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 it was necessary to perform a number of tasks. First, according to months, the fire records, fire types and fire distribution of the city centre between the years 2005 to 2008 were examined and analysed. Second, related fire data were imported into a computer environment as a GIS supported database. Later, the data in the database was visualized, analysed 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 analysed. The local fire occurences showed that 51.50% of the area was under low risk, 34.40% of the area was under moderate risk and 14.10% of the area was under high risk. Additionally, spatial queries were performed and pixel-based risk maps were produced.

2. Materials and methods

The GIS-based fire analysis method comprises some procedural steps, such as optimal location modelling, time modelling, incident trend modelling data collecting, data modelling and analysis/queries.

2.1 Fire risk analysis with GIS techniques

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 (AHP) and GIS. The authors stated that using models and software in urban planning has become prevalent in response to the complex dimension of urban issues and the role of many different indicators in this field. Yang *et al.* (2004) also carried out 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. 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). Fire station locations, the shortest path and incident density analysis are important steps for effective fire analysis. In this context, forming optimal location models is very important and this is discussed in the next section.

2.2 Optimal location model

Optimal locations were primarily modelled by Launhardt and Weber (Weber, 1909) to determine the optimal locations for industry plants, according to access to markets and raw materials within a continuous area of possibilities, and in order to minimize the transport costs to serve a spatially distributed demand. Optimal location theory and modelling of facilities has seen important developments since the 1980s and allow analysing the spatial organisation of human activities (Carreras and Serra, 1997). The transport network often

plays an important role in these models (Thomas, 2002).Within the large variety of location problems reviewed by ReVelle and Eiselt (2005), one can distinguish between two types of models, those dealing with d-dimensional space and those dealing with networks. Network-based measures are determined by summing the lengths of links or other criteria related to the length (e.g. distance-time, distance-cost). Better than coordinate-based measures (like straight distance), it takes into account the heterogeneity of space between starting and ending points along the network (Smith, 2003). The characteristics of the transport infrastructures enables accurate modelling of the cost of travel between locations, which is likely not to be uniform along the road network.

Within network facility location problems, network-based plant and warehouse location studies have been developed since the 1960s, which mainly emphasises the minimum distance location of facilities (called p-facilities) on a network of nodes, known as the p-median problems (Daskin, 1995; Thomas, 2002; Torsten and Densham, 2003; ReVelle and Eiselt, 2005). This has lead to the development of a variety of algorithms to address specific p-median problems (e.g. Kariv and Hakimi, 1979; Peters, 1996). More recently, particularly in retail location problems, the p-median model is typically applied when locating p facilities to serve demand, generally disperse (e.g. multiple points customer) in order to minimize the aggregate transportation cost (Daskin, 1995; Ghosh et al., 1995).

2.3 Time modelling

Utilising a fire station layer and a street layer, response time analysis can be performed. A street layer is often represented in GIS as a series of lines that intersect on the map, creating a GIS street network. Each street line segment between intersections contains attribute information, such as road type, distance and travel speeds (miles or kilometres per hour). This allows users to identify a station location, specify a travel time and run a network analysis. The result will be displayed by an irregular polygon around the station that illustrates where the fire apparatus could travel in any direction for the specified time. This type of analysis can be performed on a single station or simultaneously on all stations to analyse gaps in coverage, establish run orders and more (ESRI, 2006).

2.4 Incident trend modelling

Incident trend analysis can be done quickly, displayed logically and understood easily. For example, a GIS user could request to see arson fires that occurred between the hours of 1:00 a.m. and 5:00 a.m. on Saturdays in fire districts 1 and 2. GIS will interrogate the record database and place points on the map that match the request. These types of analyses provide decision support for issues related to fire prevention, staffing requirements and apparatus placement/deployment (ESRI, 2007).

2.5 Data collecting

GIS software adds intelligence to spatial data, whether the data is generated in the field with GPS or remotely with lidar and photogrammetry. You can enter raw data, measurements and field sketches directly into the GIS, enabling you to efficiently manage your data in a geodatabase with other spatial information. You can use GIS technology for collecting, importing, converting and storing spatial measurement and computational fabrics. You can

integrate computations, such as COGO (COGO is a ArcGIS extension used in civil engineering or surveying for solving cooridante geometry problems). The COGO extension provides a dialogue for setting common properties for the coordinating geometry tools and traverse least squares, and pre-existing networks, as well as importing spatial data feature classes and relationships (ESRI, 2006).

2.6 Data modelling

Data models are the rules the GIS follows, such as "county lines do not overlap", and are essential for defining what is in the GIS, as well as supporting the use of GIS software. All spatial data models fall into two basic categories:

1. Vector data model: discrete features, such as customer locations and data summarised by area, are usually represented using the vector model.
2. Raster data model: continuous numeric values, such as elevation, and continuous categories, such as vegetation types, are represented using the raster model (URL1, 2011).

2.7 The importance of a 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, analyse 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 1.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 (see Table 2).
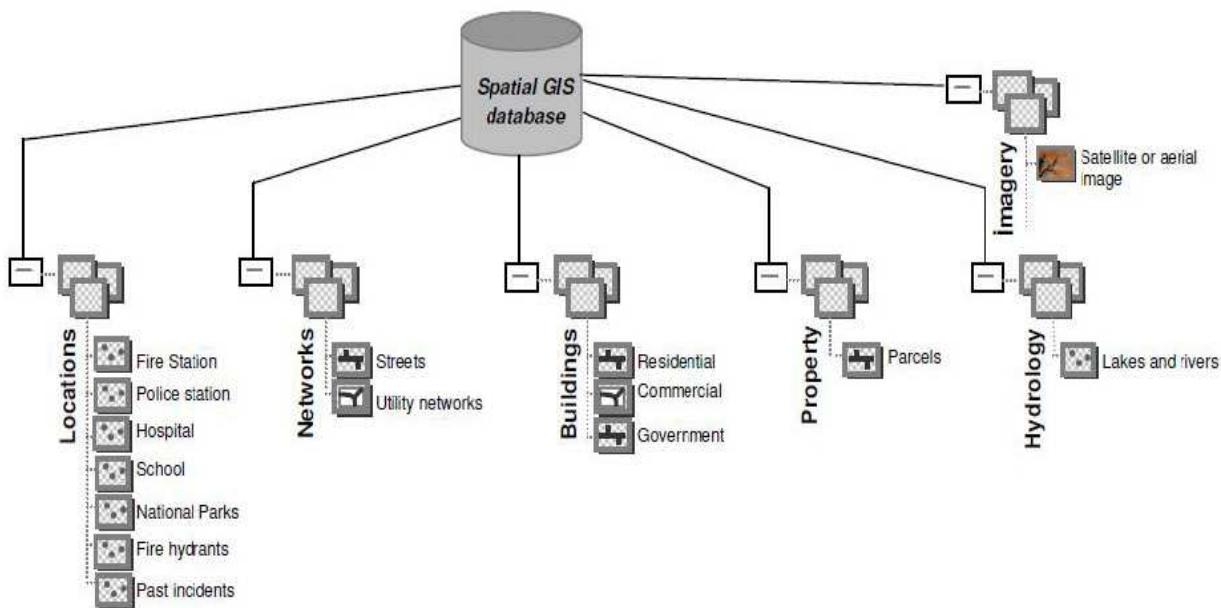

Fig. 1. Main spatial data layers used in GIS related to fire incidents (Nisanci, 2010).

A Fire Information System (FIS) which includes all spatial and non-spatial data related to fire (see Figure 2) should be connected to the GIS database so that when needed any query can be acted upon to 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 fires in many countries is not to be underestimated. If we can gain information about the number of residents and their physical or mental condition via a social health database, this can save many lives. Additional information on the residents should be obtained from the civil registry, social health organisations and amalgamated into the FIS database. Furthermore, the FIS should be able to access information in the GIS database at the moment of the fire about the building (architectural details including fire escapes, building structural projects, 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 2. In this way, through this distributed data model, the FIS will be optimized and work more efficiently.

In order to maximize the fire fighting ability of the Fire Brigade and thus save lives, prevent injury and reduce economic losses, 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 by finding answer to questions such as how to prepare for fires in areas where fire truck access is restricted (or prevented), ascertaining where there is a need for more fire hydrants and whether maintenance is required in existing hydrants, if the current distribution of fire stations is adequate and if they are appropriately located and where the areas of particular risk are. This paper describes the development of the FIS model for Trabzon city using GIS technology and shows how appropriate databases can be created to respond to queries and provide information for analysis (Nisanci, 2010).
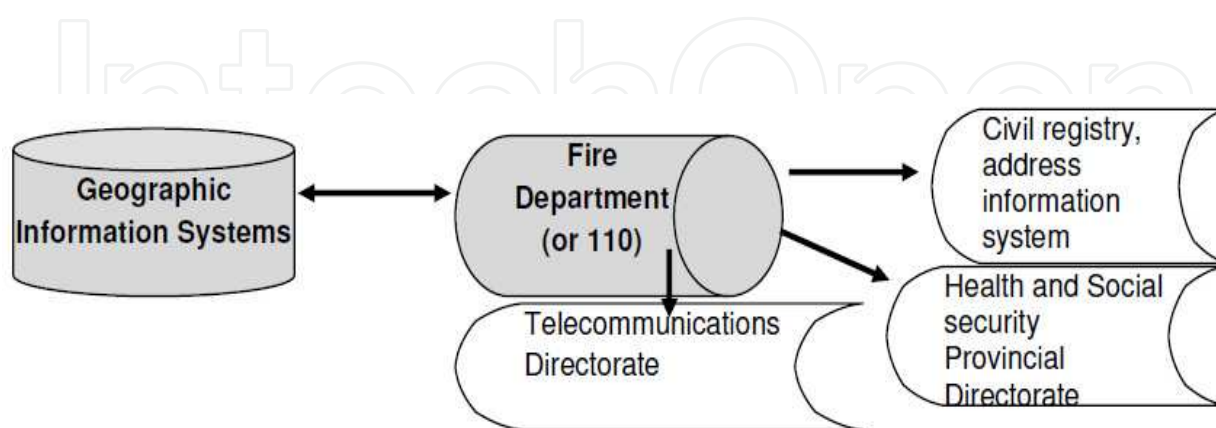
Fig. 2. Basic structure of distributed data model for FIS.

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 is fire exist?	
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 vulnerable people living in house (children, elderly, disabled etc.)?	Update database information.
	Location of the nearest first aid centre (hospital, health centre)?	
Where are the water depots and other water resources in the 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-causally, economic damage, etc).		Fire database to be updated.

Table 2. Fire information system needs analysis (Nisanci, 2010).

2.8 Fire analysis for Trabzon city

The city centre of Trabzon in Turkey (see Figure 3) 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 included: 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 the database. As can be seen in Table 3, the number of fires has increased since 2002 and although the number of deaths was only two over the whole period, the number of people injured has increased (Nisanci, 2010).

From 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.

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

Table 3. Number of fires in Trabzon city centre from 2002 to 2008 (Nisanci, 2010).
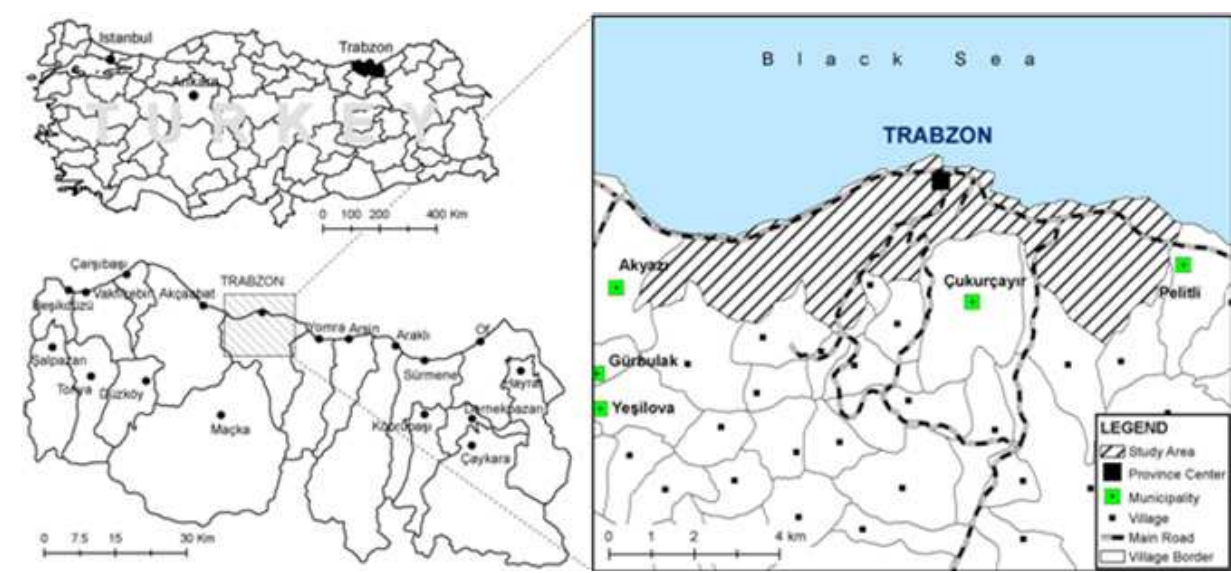
Fig. 3. Study area.

3. Case study and results

In Turkey, access roads to buildings for fire trucks are 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 manoeuvre (Figure 4).

3.1 Spatial distribution analysis of hydrants

An important layer of an FIS is placement of hydrants. In the study area, the total number and location of hydrants were not known. Therefore in this study, using the Topcon GMS 2 DPGS device it's static accuracy is 3mm horizontal and 4mm vertical, the locations of known hydrants was found and transferred to the 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 the database.

In clause 3 and 11 of Article 95 of the regulation on protection of buildings from fire, hydrants are to be placed within the 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 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."

From the fire intensity analysis produced as part of the study the Kermekaya district of Trabzon city was determined to be in very high risk area, it is therefore concluded that the existing four hydrants are insufficient and the distance between these fire taps is much greater 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.
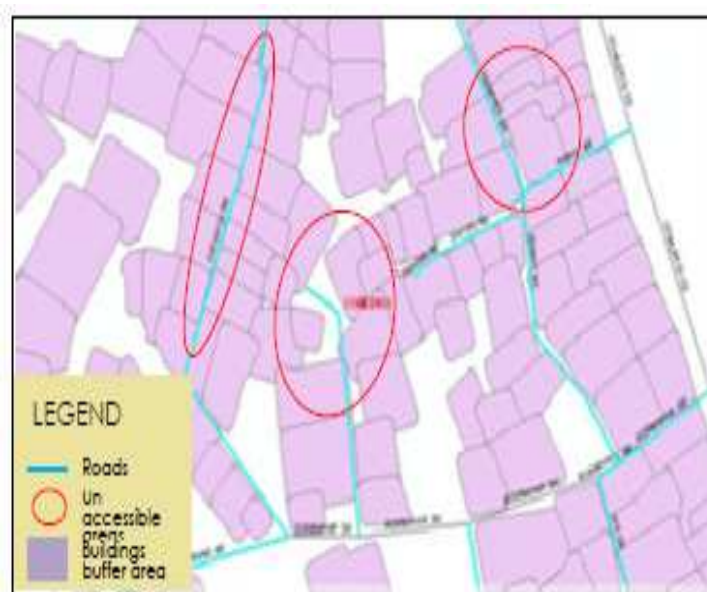

Fig. 4. Sample for streets that a fire truck cannot enter (Cömlekci district, Ortanca and Cemiyet Street) (Nisanci, 2010).

Fig. 5. Example of the lack of visibility of some hydrants covered by plan (Nisanci, 2010).
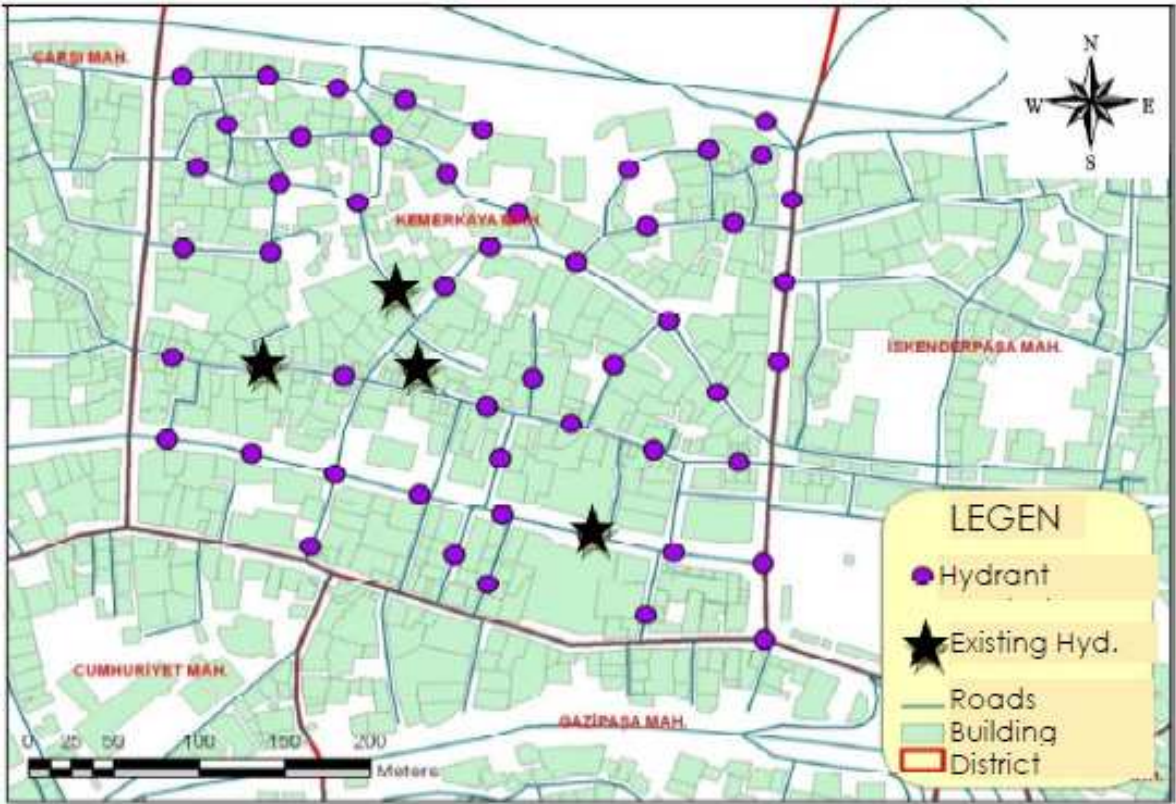

Fig. 6. Spatial distribution of fire hydrants in the Kemerkaya district in Trabzon city
(Nisanci, 2010).

3.2 Analysis of the fire number according to months

Between 2002-2008 fires per month were analysed and a 'Fire Distribution According to Months' database was created (Table 4).
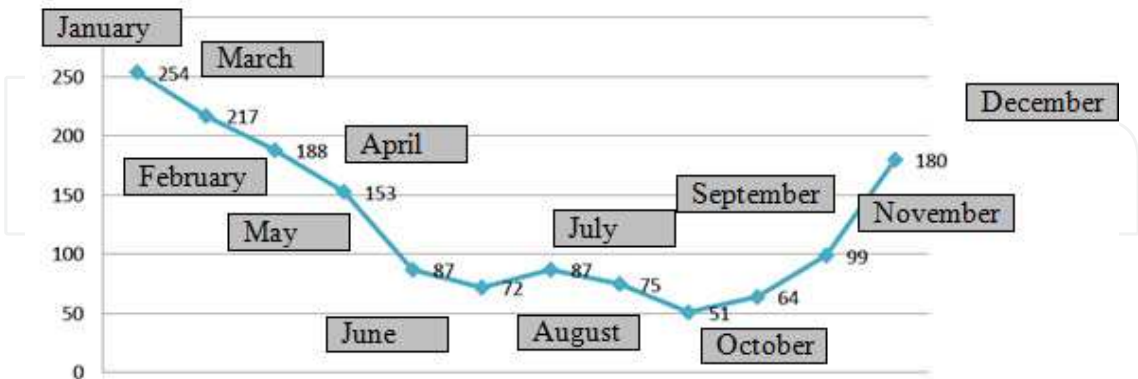

Table 4. The results of this analysis show fires were seen more in the winter months, such as December-January-February.

3.3 Analysis of accessibility to fire in the shortest time

Access to a fire incident and making an intervention in the shortest time has great importance for extinguishing a fire. In this analysis, the areas that a fire truck can reach according to certain time intervals and speed were determined (Figure 7). In this analysis, the speed of a fire truck, its access time to the incident site (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 3, 5 and 7 min were determined using a truck traveling at 45 km/h. Accordingly created maps are shown below (see Figures 8-9-10). 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.
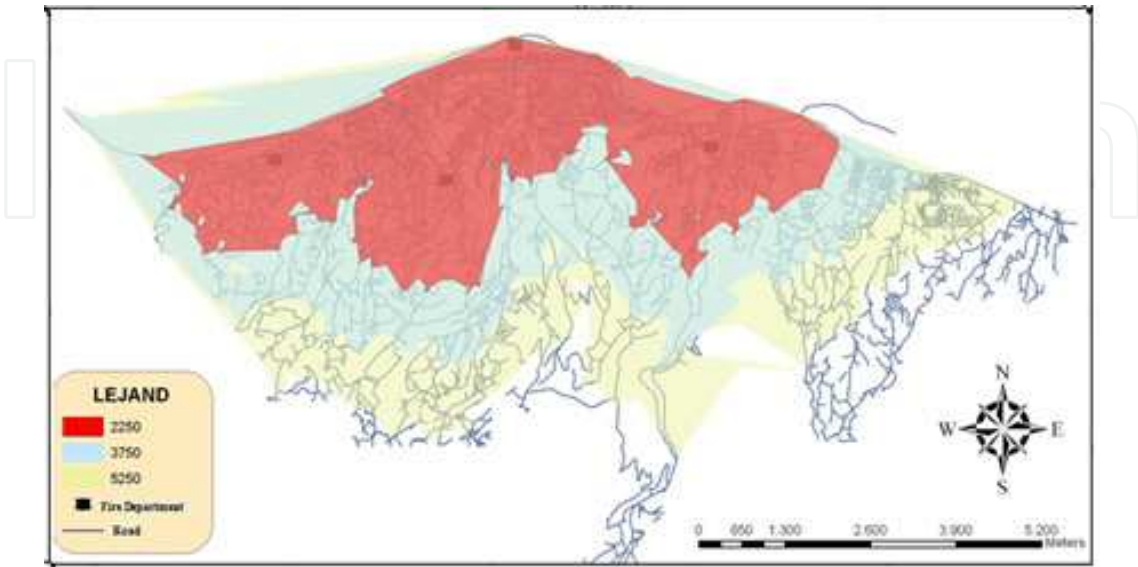
Fig. 7. A regional map of fire truck access according to time.
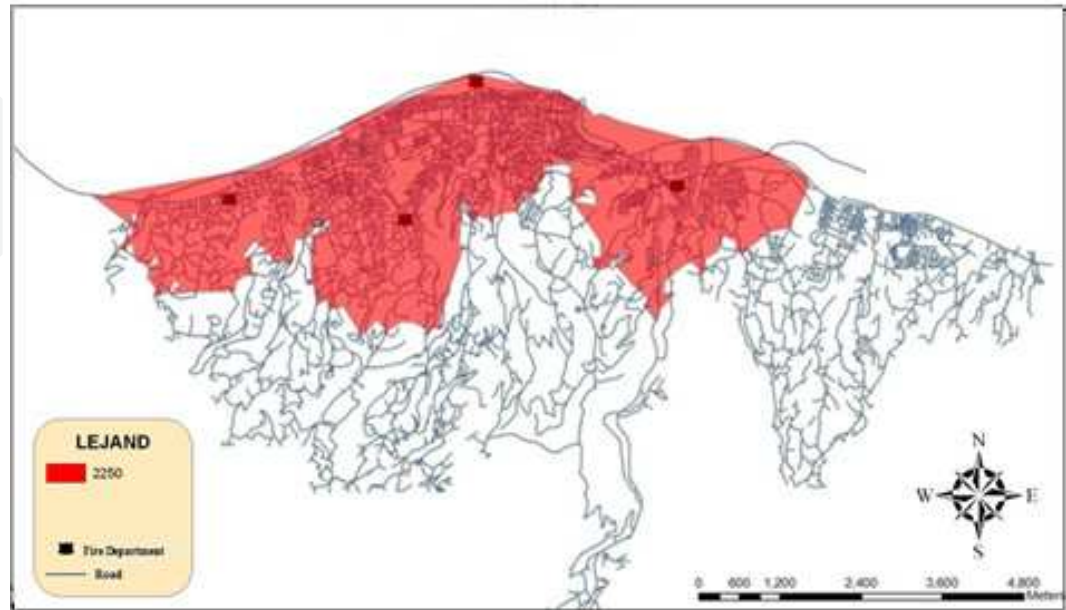
Fig. 8. The areas that a fire truck can access within 3 min in Trabzon city.
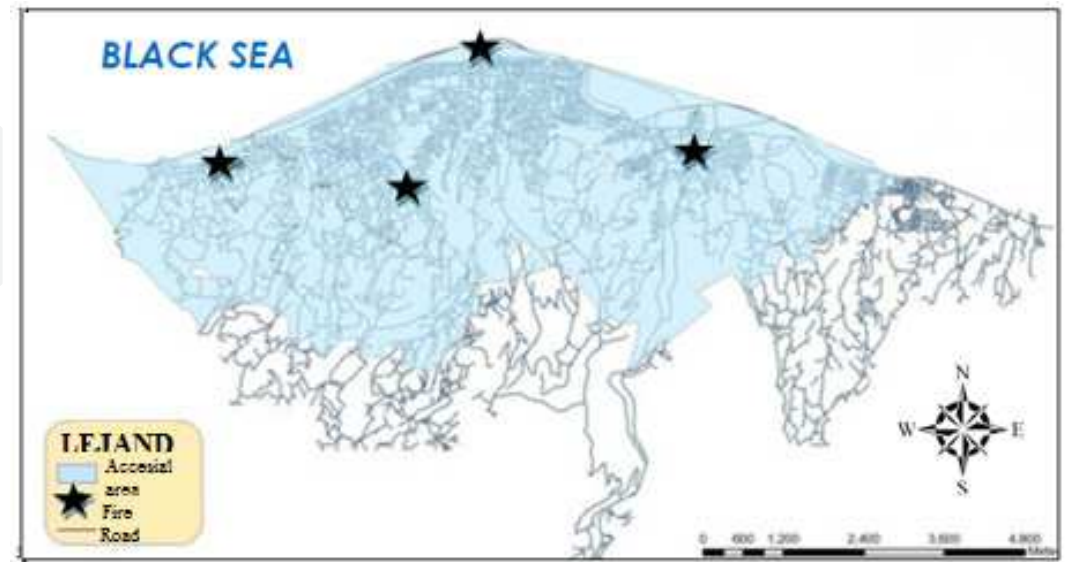

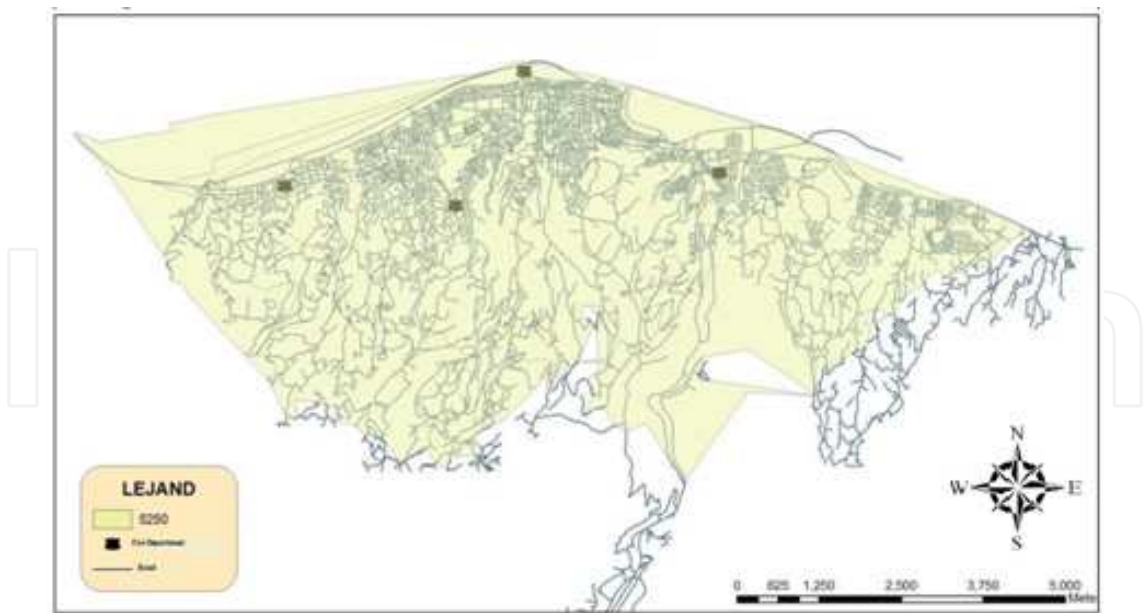Fig. 9. The areas that a fire truck can access within 5 min in Trabzon city.

Fig. 10. The areas that a fire truck can access within 7 min in Trabzon city.

3.4 Analysis of fire types

Fire types between 2002-2008 were analysed by creating a database from fire reports as shown in Table 5. According to this fire types created map are shown below (Figure 11).
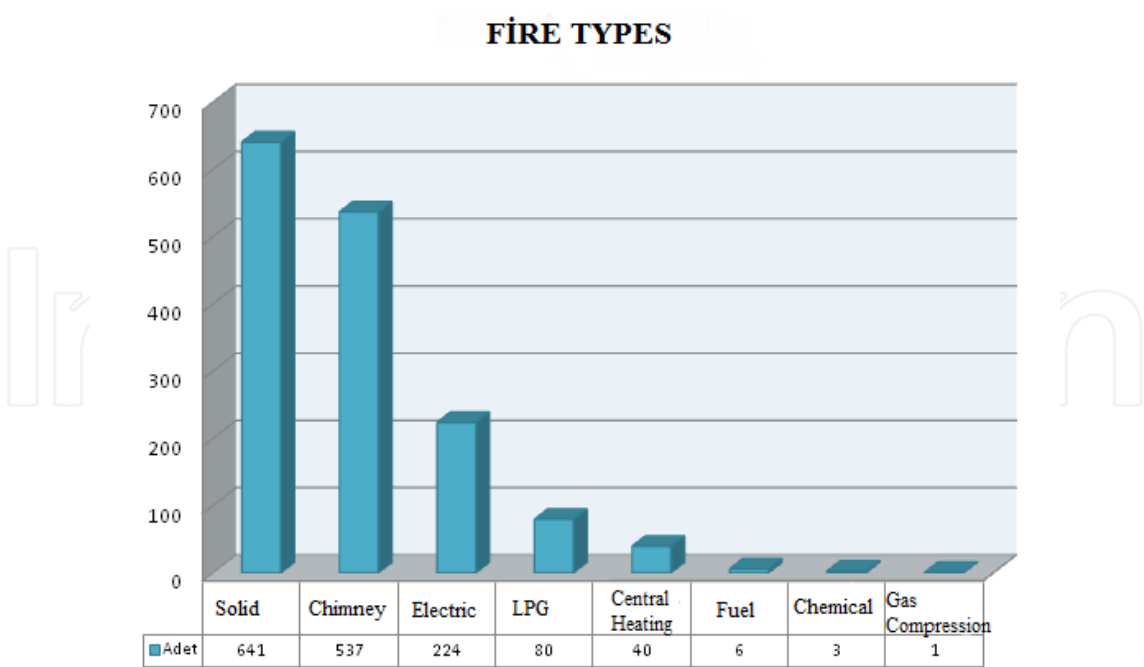

	Solid	Chimney	Electric	LPG	Central Heating	Fuel	Chemical	Gas Compression
Adet	641	537	224	80	40	6	3	1

Table 5. Types of fire that occurred between 2002-2008 (Nisanci, 2010).
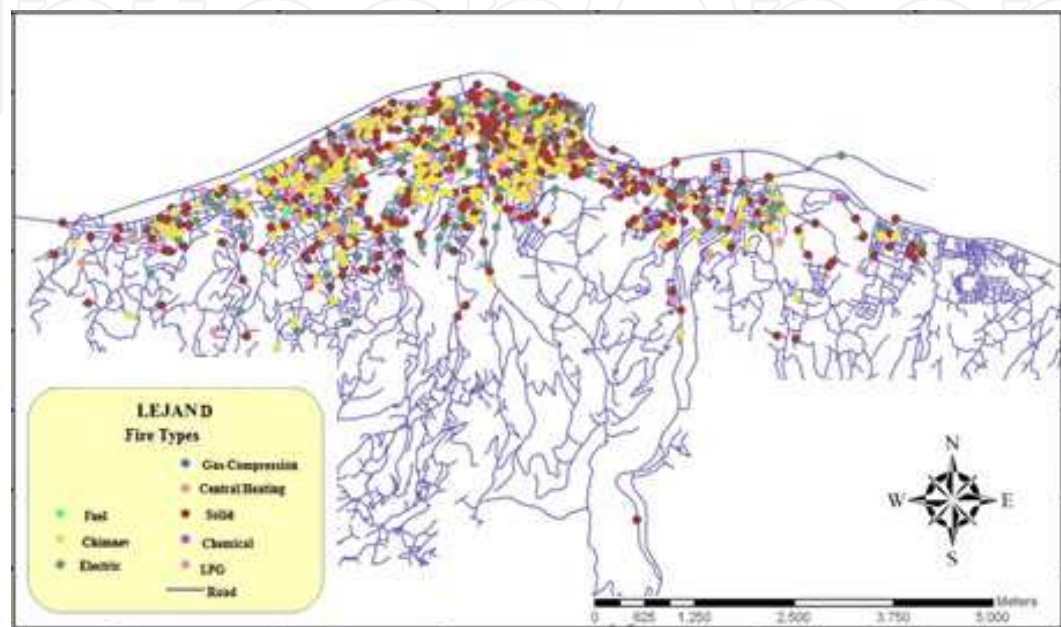
Fig. 11. Fire types map.

3.5 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 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 12).

3.6 Determination of fire density

Fire density is determined according to the numbers of 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 QuickBird satellite image of the city (Figure 13). Then this network was 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 the 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 centre outwards (Figure 13). In other words, there is an inverse proportion between the distance to the city centre and number of fires and the density. The reason for this distribution arises from the city centre being an old settlement, with old buildings and heating being provided by coal or gas burning stoves.
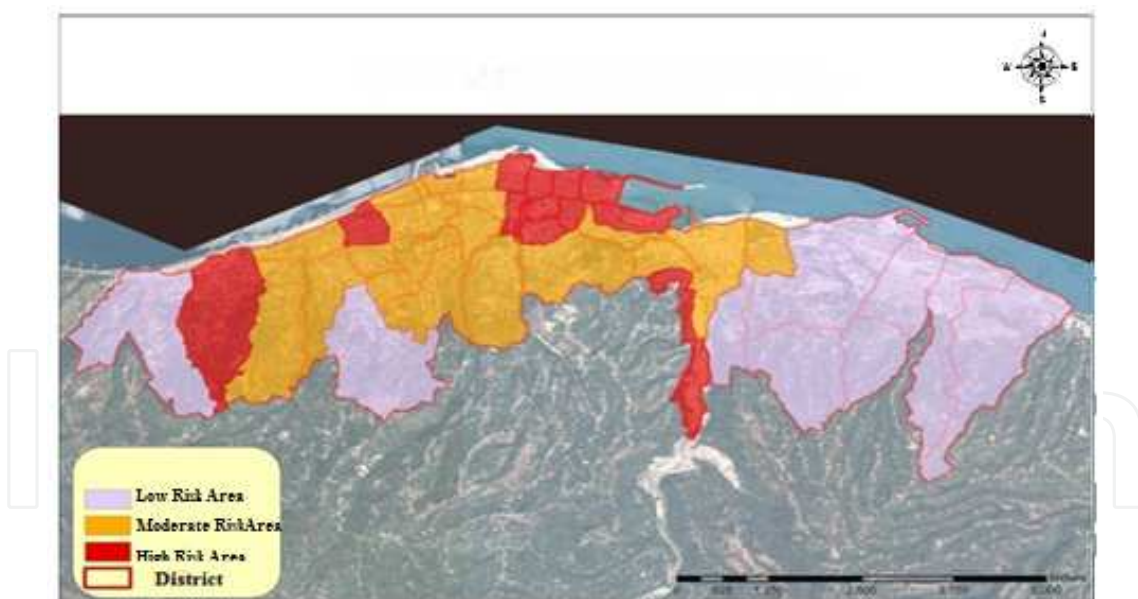

Fig. 12. High risk places found in and around Trabzon city centre (Nisanci, 2010).
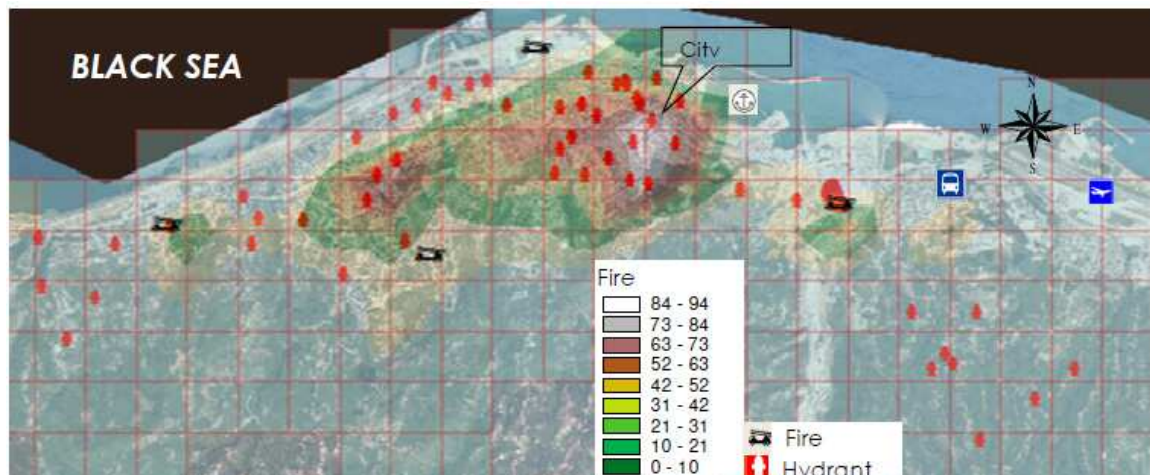
Fig. 13. Fire density risk map of Trabzon city and vicinity (Nisanci, 2010).

4. Conclusion and future work

In conclusion, the fires that occurred in Trabzon city were recorded according to the numbering system and on a street basis in a GIS database. It is now possible to facilitate a more advanced 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 stations and hydrant locations, roads, satellite images with high resolution, written and verbal details relating to buildings (such as residential, official facilities, factories, depots). Furthermore, a verbal database from attribute data was created, such as fire types, fire number etc. It was found that the spatial information of hydrants is deficient and 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.

In this study, the GIS analysis showed that were local fire occurences in 51.50% of the area under low risk, 34.40% of the area under moderate risk and 14.10% of the area under high risk. Problems 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 concluded that the measures required had not taken in the intensive fire areas found at the end of the GIS analysis, although it is evident from fire records that the intensity of fires in these regions are high.

Today, fire is an important risk factor for urban areas. For this reason, firstly fire risk areas are established by using spatial databases in cities. The use of traditional statistical methods with address data, the number of fires and so on, is not adequate as a modern solution. Determination of the optimum route, accessibility analysis, emergency response management applications should be made by performing GIS-based fire scenarios on the

risk areas. Especially in risk areas, fire hydrant areas should be optimized, and associated with a spatial fire database. In the event of fire, in order to minimize loss of life and property, it should be ensured that areas such as shopping centres, hospitals, schools, hotels and convention centres have fire escape plans and floor plans added to the fire databases.

5. Acknowledgments

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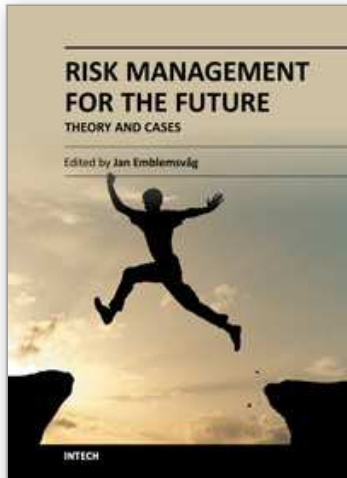
Risk Management for the Future - Theory and Cases

Edited by Dr Jan Emblemsvåg

A large part of academic literature, business literature as well as practices in real life are resting on the assumption that uncertainty and risk does not exist. We all know that this is not true, yet, a whole variety of methods, tools and practices are not attuned to the fact that the future is uncertain and that risks are all around us. However, despite risk management entering the agenda some decades ago, it has introduced risks on its own as illustrated by the financial crisis. Here is a book that goes beyond risk management as it is today and tries to discuss what needs to be improved further. The book also offers some cases.

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