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Multi-criteria site selection for fire services: the interaction with analytic hierarchy process and geographic information systems

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Abstract. This study combines AHP and GIS to provide decision makers with a model to ensure optimal site location(s) for fire stations selected. The roles of AHP and GIS in determining optimal locations are explained, criteria for site selection are outlined, and case study results for finding the optimal fire station locations in Istanbul, Turkey are included. The city of Istanbul has about 13 million residents and is the largest and most populated city in Turkey. The rapid and constant growth of Istanbul has resulted in the increased number of fire related cases. Fire incidents tend to increase year by year in parallel with city expansion, population and hazardous material facilities. Istanbul has seen a rise in reported fire incidents from 12 769 in 1994 to 30 089 in 2009 according to the interim report of Istanbul Metropolitan Municipality Department of Fire Brigade. The average response time was approximately 7 min 3 s in 2009. The goal of this study is to propose optimal sites for new fire station creation to allow the Fire Brigade in Istanbul to reduce the average response time to 5 min or less. After determining the necessity of suggesting additional fire stations, the following steps are taken into account: six criteria are considered in this analysis. They are: High Population Density (HPD); Proximity to Main Roads (PMR); Distance from Existing Fire Stations (DEF); Distance from Hazardous Material Facilities (DHM); Wooden Building Density (WBD); and Distance from the Areas Subjected to Earthquake Risk (DER). DHM criterion, with the weight of 40%, is the most important criterion in this analysis. The remaining criteria have a weight range from 9% to 16%. Moreover, the following steps are performed: representation of criterion map layers in GIS environment; classification of raster datasets; calculating the result raster map (suitability map for potential fire stations); and offering a model that supports decision makers in selecting fire station sites. The existing 35 fire stations are used and 17 fire stations are newly suggested in the study area.

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1 Introduction

The general objective of Multi-criteria Decision Making (MCDM) is to assist the decision-maker (DM) in selecting the "best" alternative from the number of feasible choice-alternatives under the presence of multiple choice criteria and diverse criterion priorities. The multicriterion choice can be attributed to many spatial decision-making problems involving search and location/allocation of natural resources. These problems, often analysed in GIS, include location/site selection for: service facilities, retail outlets, critical areas, hazardous waste disposal sites and emergency service locations (Jankowski, 1995). A site selection decision is structured according to the following steps: (1) determining the criteria that are used in evaluating the alternatives; (2) describing relevant criteria in decision making process; (3) developing the multi-criteria site selection alternatives; and (4) evaluating the alternatives and making the final site selection decision (Ertugrul and Karakaşoğlu, 2008).

Site selection is a typical MCDM problem in which preference among performance criteria plays a key role in the final decision. To assess the decision-maker's preference with a preference model, many efforts have been made to develop the theory and methodology for preference assessment (Yang and Lee, 1997). One of the most preferred approaches is Analytic Hierarchy Process (AHP) which has been developed by Saaty (1980).

In AHP, a decision problem is first decomposed into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. The elements of the hierarchy can relate to any aspect of the decision problem. Once the hierarchy is built, the decision makers

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systematically evaluate its various elements by comparing them to one another two at a time. Given a pairwise comparison, the analysis involves three steps: (1) developing a comparison matrix at each level of the hierarchy starting from second level to the last level, (2) computing the relative weights for each element of the hierarchy, and (3) estimating the consistency ratio to check the consistency of the judgements (Saaty, 1980).

The AHP site selection solution process starts with the identification of the pertinent site selection factors. These factors are then structured into hierarchy descending from an overall objective to various criteria and sub-criteria in successive levels. The priority weights of structured site selection factors are then determined through pairwise comparisons to reflect the judgments and relative preferences of different stakeholders. The site selection decision ends when the decision makers provide their final recommendation for the most suitable site(s) with the analysis results (Yang and Lee, 1997).

The site selection process involves making spatial decisions. GIS, with the capabilities of data acquisition, storage, retrieval, manipulation, analysis and visualization, has been used for supporting spatial decision-making. Siddiqui et al. (1996) were the first to combine GIS and AHP procedure to aid in site selection. The authors developed the spatial-AHP concept which uses selection criteria and area attributes recorded on GIS data maps to identify and rank potential landfill areas. In recent years, there have been a number of papers published about site selection using spatial information technologies and AHP (Guigin et al., 2009; Sener et al., 2006; Kontos et al., 2005; Jun, 2000; Reveshti and Heidari, 2007; Eldrandaly et al., 2003).

Kontos et al. (2005) described a methodology which comprises several methods from different scientific fields such as multiple criteria analysis, GIS, spatial analysis and spatial statistics to evaluate the suitability of the study region in order to optimally site a landfill. Sener et al. (2006) have also dealt with landfill site selection problems considering several map layers from topography to land use. They have used GIS and multicriteria decision-making methods such as AHP and weighted linear combination in their study. Guigin et al. (2009) have proposed a hierarchical model to incorporate information from environmental and economic factors, and have offered this model as a reference for landfill site selection in the future. Their study takes into account both environmental and economic criteria, the process by which the model selects landfill sites is suitable for rapidly developing cities in developing countries. Raveshti and Heidari (2007) have proposed fire extinguisher stations for the city of Zanjan in Iran by using AHP and network analysis method in ArcGIS. Jun (2000) have developed a framework for integrating the strengths of GIS, expert systems and the AHP to incorporate the decision maker's preferences on a range of factors used in finding optimally suitable sites. Eldrandaly et al. (2003) have suggested a decision support system to select

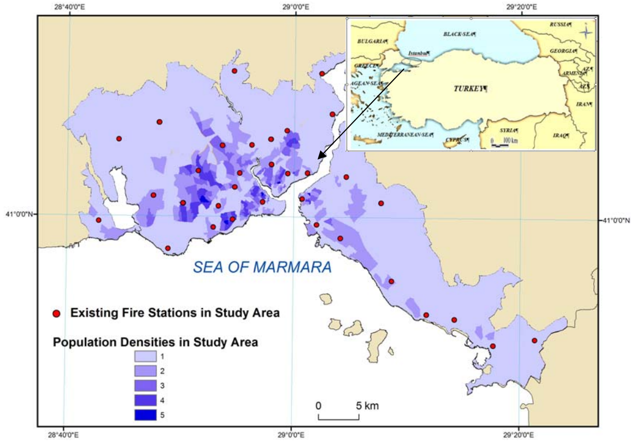

Fig. 1. Study area with population densities and existing fire stations.

the location of the industrial sites in which expert systems, GIS and the AHP were successfully integrated by using the component object model technology.

2 Study area

Istanbul, with an area of around 6000 km^2, is the most crowded city in Turkey (Fig. 1). According to the 2009 official census data based on the "Address Based Population Registration System, which was conducted by the Turkish Statistical Institute", internal migration to Istanbul still continues with an increasing rate. The study shows that the population of Istanbul has increased in the last seven years and reached around 13 million residents. Population density of Istanbul is around 2400 km^2 with the population change of around 3.2% per year (www.tuik.gov.tr[1]).

The urban landscape of Istanbul is constantly changing. Istanbul can now be considered as a mega city expanding further with new neighborhoods and districts. In recent decades, numerous tall structures were built around the city to accommodate a rapid growth in population. The rapid growth and development in Istanbul creates an increase in the number of emergency incidents such as fires and fire related incidents. In this study, we consider the city centre of Istanbul which is highly populated compared to its towns and villages. Our assessment is based on the Decree Law No. 3030 concerning "the Administration of Metropolitan Municipalities" and we have selected the area covered by mentioned Decree Law.

The mission of the Fire Brigade of Istanbul is to serve the city and its residential areas in order to reduce loss of life and material damages which are caused by fires and natural disasters. The national fire protection standards for urban areas are based on a response time of five minutes or less. The Department increased the number of fire stations

[1]Prime Ministry Republic of Turkey, Turkish Statistical Institute, last access: 23 February 2010

from 38 to 71, and the number of staff from 1852 to 4906 between years 2004 and 2009. According to interim report of the Istanbul Metropolitan Municipality Department of Fire Brigade, 30 089 fire incidents occurred in 2009 (IMM, 2009). Fire incidents tend to increase year by year in parallel with city expansion, population and hazardous material facilities. 12 769 fire incidents occurred in 1994 and it reached 30 089 in 2009. With existing fire stations, the Department of the Fire Brigade responded to fire incidents in 7 min 3 s based on the interim report mentioned above. The Department aims to reduce fire response time to 5 min or less to improve fire response activity.

3 Methodology

The main objective of this study is to suggest a model that supports decision makers in decision-making to determine the optimal sites for fire stations. In this context, these steps are followed (see Fig. 2):

1. definition of the problem/objective (site selection for fire stations);
2. considering the potential criteria for finding the optimal sites of fire stations;
3. data collection, preparation and transferring to GIS environment;
4. creation of raster datasets representing the regionalized criteria;
5. classification of raster datasets;
6. establishment of preference matrix, assigning preference values to the relevant criteria by using the pairwise comparison feature of AHP;
7. determination of criteria weights by calculating eigenvalues and eigenvectors of the preference matrix which was evaluated by 10 academic-related decision-maker groups;
8. calculating the criteria priorities/weights values by using the synthesis of priorities and calculating the overall composite weights;
9. obtaining the result raster suitability map for potential fire stations by means of weighted overlay technique for all raster datasets;
10. offering a system that supports decision makers in determining the optimal locations of fire stations (Erden, 2009).

Six criteria have been considered from the project report concerning critical risk areas and station locations in Istanbul (IMM, 1989). Gay and Siegel (1987) and Johnston (1999) also suggest the relevant criteria should include distance between fire stations, population densities and special hazards

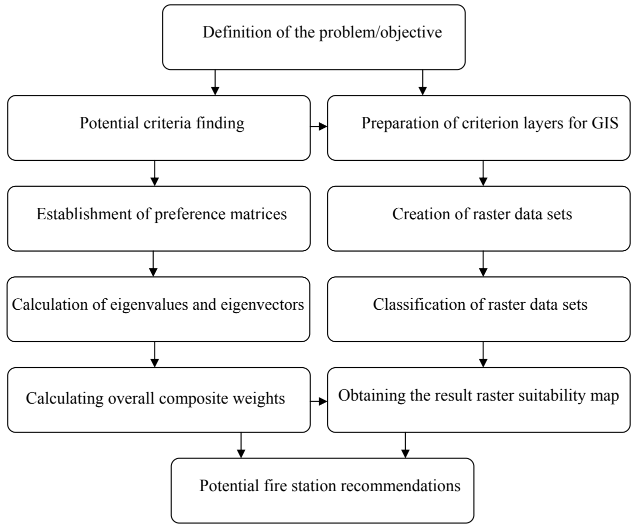

Fig. 2. The conceptional flow chart of the methodology.

while determining the location and number of fire stations in a community. They recommend a comprehensive planning approach that reviews the entire operation of a fire department in order to provide the most cost-effective system of fire protection possible.

The most important criteria are the distances between fire stations, population densities and the level of risk in the city coverage area. Since Istanbul is a metropolitan city and it has quite high population densities, population density is taken into consideration for the first criteria. Road accessibility is another important criterion for fire response activities and this criterion is also considered. Istanbul also has heavy industrial activities and it has a lot of hazardous material facilities. These locations are considered as a criterion in this analysis. Istanbul is also a very old city and it has a lot of old, wooden buildings, they are also added to the analysis. Moreover, the other important source of the risk in Istanbul is the unprecedented increase of the probable occurrence of a large earthquake. The inevitability of the occurrence of such a large earthquake in Istanbul makes it imperative that certain preparedness and emergency procedures be contrived prior to an earthquake disaster (Erdik et al., 2003). We consider the earthquake risk in selecting the fire stations in this analysis, too. Another reason for considering and processing six criteria is based on Miller's Law (Miller, 1956). Miller (1956) indicated that the capacity of human short-term memory is seven separate items, plus or minus two. The brain of a regular human can simultaneously process, differentiate and deal with at most 7 factors. For some people this limit can be decreased to 5, for the rest it can be increased to 9. With this in mind, we consider six criteria in our assessment. Criteria considered can be seen in Fig. 3.

The above-mentioned criteria with their abbreviations are High Population Density (HPD), Proximity to Main Roads (PMR), Distance from Existing Fire Stations (DEF),

Table 1. Criteria value ranges and their assigned class values.

Criteria	Class values				
	1	2	3	4	5
HPD (people per hectare)	0.0–186.4	186.4–372.8	372.8–559.2	559.2–745.6	745.6–932.0
PMR (metre)	300–240	240–180	180–120	120–60	60–0
DEF (covered areas in minutes)	1	2	3	4	5
DHM (number in per district)	0–4	4–8	8–12	12–16	16–19
WBD (ratio in total built-up area)	0–2	2–4	4–6	6–8	8–10
DER (pga values in g)	1.0–0.8	0.8–0.6	0.6–0.4	0.4–0.2	0.2–0.0

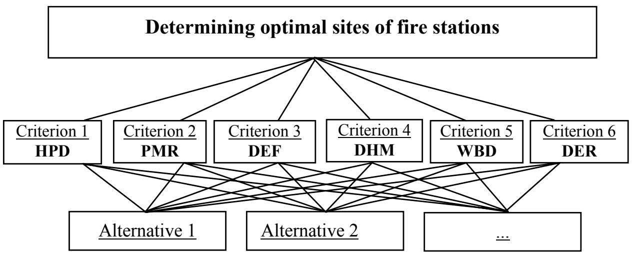

Fig. 3. Representation of the 3-level structure of objective, criteria and alternatives.

Distance from Hazardous Material Facilities (DHM), Wooden Building Density (WBD), and Distance from the Areas Subjected to Earthquake Risk (DER) (see Fig. 3).

After the criteria are considered, we calculated the criteria priorities/weights values by using the synthesis of priorities of AHP. To obtain a result raster map, we apply the weighted overlay technique. Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. The process involves the preparation of criterion maps and superimposing them on top of one another to obtain the composite configuration so as to decide upon the most suitable locations in relation to the pre-existing set of interacting factors.

4 Data preparation and analysis

After constructing the hierarchical structure of the model, the criteria for the model is designed. The map resolution unit is 50×50 m for the whole criteria considered in our assessment. HPD criterion has a value range from 0 to 932 that represents the number of people living in per hectare; and we represent hectare base data with a mapping unit of 50×50 m. PMR criterion has a value range from 0 to 300 that indicates distance values from the road segments in metres (Habibi et al., 2008). We make buffer analysis for PMR criterion that ranges from 0 to 300 m. DEF criterion has a value range from 1 to 5 that represents service areas covered from each fire station in minutes. NFPA (2001) and Petersen (1998) suggest that industry standards for fire response times range from four to six minutes. This is because it takes additional minutes to size up the situation, deployment and initiate search and rescue. We consider a 5-min fire response in terms of mentioned publications. DHM criterion has a value range from 0 to 19 that shows the number of hazardous material facilities per district. WBD criterion has a value range from 0 to 10 that represents the ratio of wooden building density in a total built-up area, and DER criterion has a value range from 0.0 to 1.0 that represents peak ground acceleration values in g (see Table 1). The measurement units of the variables HPD, PMR, DEF, DHM, WBD and DER are hectare, metre, minute, number, ratio, and g, respectively.

Schoppmeyer (1978) suggests that tone scale should not include more than seven tone values in cartographic representation. Therefore, we establish 5 classes of representation in our assessment. After determining criteria value ranges, the ranking of the class values from 1 to 5 is assigned as equal interval breaks. There are some data classification methods including equal interval, quantile, natural breaks (jenks) and standard deviation in GIS environment. The equal interval classification divides the total range of features from maximum to minimum into equal subranges. This creates an easy to understand legend and works best with continuously distributed data. This method is good for easier to interpret data especially for familiar values, like percentages. Our criterion data are well-suited with the equal interval data classification method given the absence of threshold values in the methodology. Criteria value ranges and the ranking of the corresponding class values are represented in Table 1 as well.

The format of input data for each criterion map layers is vector-based polygon data structure. The polygon based data covers the borders of per quarters in the study area for each criterion map layers. The data of criterion map layers are obtained from JICA and IMM (2002) project regarding the study on a disaster prevention/mitigation basic plan in Istanbul including microzonation studies. DHM, WBD, and PMR criteria are obtained from JICA and IMM (2002) project, which are reproduced by their study team from the map scale of 1:5000 of the study area. Population data are also in vector based polygon data structure and they are obtained from Ozcan (2008) and Turkish Statistical Institute (TUIK). Population data refer to the borders of each quarter in the study

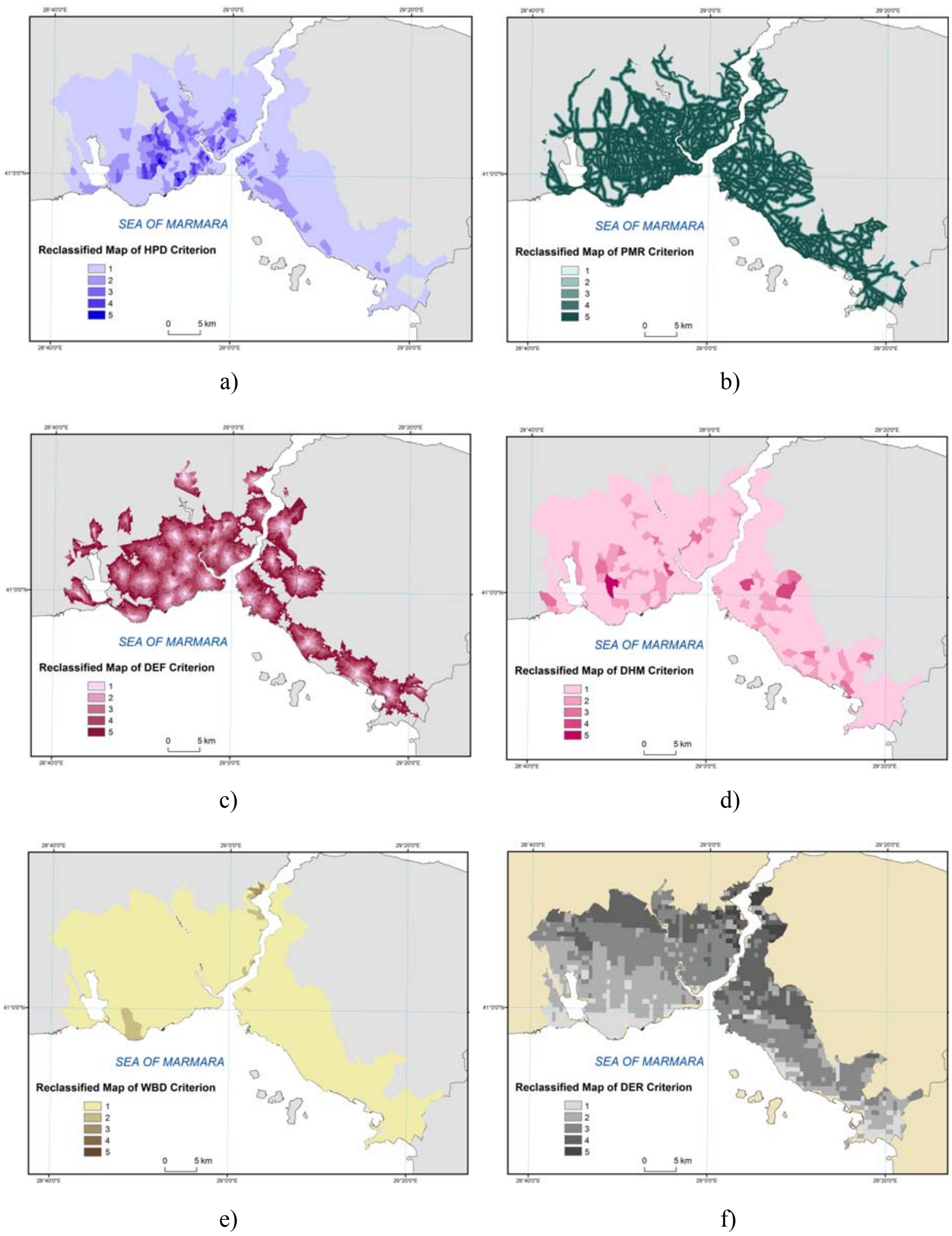

Fig. 4. Reclassified maps of **(a)** HPD, **(b)** PMR, **(c)** DEF, **(d)** DHM, **(e)** WBD and **(f)** DER criteria.

area. Population densities are used in this study, which are obtained from dividing the census data of each quarter by built-up area of a corresponding quarter in hectare. The locations of existing fire stations for DEF criterion are obtained from Istanbul Metropolitan Municipality; and DER criterion is obtained from HAZTURK project (Karaman et al., 2008) with the mapping resolution of 50×50 m.

After criterion map layers are represented, vector-based polygon data structures are converted to raster-based data structures. The territorial unit of 50×50 m is chosen for the analysis. This territorial unit is sufficient for a suitability analysis of such a large study area, therefore, we propose the area for a new fire station and not the exact location for it. Based on assigned class values of each criterion, each map layer is reclassified with the values from 1 to 5 (see Table 1).

The criterion map layers of HPD, PMR, DHM, WBD and DER with assigned class values are represented in Fig. 4a–b and d–f, respectively.

Service area analysis is performed by utilizing fire station layer and road layer. Each road line segment between intersections contains attribute information such as road type, distance, and travel speeds (kilometers per hour). This allows users to identify a fire station location, specify a travel time, and run a network analysis for determining the service

Table 2. Preference (pairwise comparison) matrix for one decision maker.

Criteria	HPD	PMR	DEF	DHM	WBD	DER
HPD	1	3	6	1	1	5
PMR	0.333	1	5	0.25	0.25	3
DEF	0.167	0.2	1	0.25	0.33	3
DHM	1	4	4	1	3	6
WBD	1	4	3	0.333	1	5
DER	0.2	0.333	0.333	0.167	0.2	1
$\lambda_{max} = 6.56$			CI = 0.11		CR = 0.09 < 0.1	

Table 3. Preference (pairwise comparison) matrix for group judgment.

Criteria	HPD	PMR	DEF	DHM	WBD	DER
HPD	1	1.172	1.893	0.295	1.374	1.896
PMR	0.853	1	1.506	0.342	1.522	1.557
DEF	0.528	0.664	1	0.336	1.009	0.960
DHM	3.393	2.922	2.973	1	3.693	4.156
WBD	0.728	0.657	0.992	0.271	1	1.104
DER	0.527	0.642	1.041	0.241	0.906	1
$\lambda_{max} = 6.04$			CI = 0.009		CR = 0.007 < 0.1	

areas. In this study existing 35 fire stations are used in network analysis with travel time impedance range from 1 to 5 min. The artery speed limits of local roads, main roads and highways are 30 km/h, 60 km/h and 90 km/h, respectively. These three road types are combined and network analysis is performed. With mentioned speed limits and road segment lengths, travel times of per road segment are calculated in the attribute table of road layer and these travel times are impedances for network analysis. The criterion map layer of service areas of existing fire stations and their assigned class values are represented in Fig. 4c.

After acquisition and conversion of the data, the AHP decision model is constructed with the determination of the criteria priorities/weights that are used in GIS analysis. A questionnaire is prepared for forming the pairwise comparison matrix (see Table 2). 10 academic-related emergency management specialists filled the pairwise comparison matrix according to their opinions. Table 2 represents one of the decision-maker preference matrices.

The λ_{max} value is an important indicator in AHP and it is used as a reference index by calculating the consistency ratio (CR) of the estimated vector. At each level of hierarchy, if CR < 0.10, then pairwise comparisons are acceptable; if, however, CR ≥ 0.10, the values of ratio are indicative of inconsistent judgements. In such cases, one should reconsider and revise the original pairwise comparion matrix.

AHP also helps to incorporate a group consensus. This procedure consists of a questionnaire for comparison of each element and geometric mean to arrive at a final solution (Saaty, 1989). We computed geometric means of all paired comparison judgments for each question in order to reveal the aggregated group judgments (see Table 3).

After calculating the λ_{max}, CI, CR indices for a group decision-making, we computed weight vector for six criteria as follows (see Table 4).

As seen in Table 4, all criteria priority/weight values sum to 1. We used these priority/weight values for multicriteria site analysis in GIS environment. ArcGIS 9.2 platform and Spatial Analyst extension and weighted overlay technique are used in analysis.

Table 4. Criteria priority/weight vector.

Criteria	Priorities/Weights
DHM	0.40 (%40)
HPD	0.16 (%16)
PMR	0.15 (%15)
DEF	0.10 (%10)
WBD	0.10 (%10)
DER	0.09 (%9)

5 Results and discussion

After class values are assigned for each criterion map layers, these criterion map layers were then overlaid with the weighted overlay technique using criteria priority/weight vector results in GIS environment. After whole procedures are achieved, a suitability map for the determination of optimal sites for fire stations is obtained (see Fig. 5). Existing and suggested fire stations can also be seen in Fig. 5.

Suitability map is also reclassified with the equal interval classification method because we produced the criterion map layers with the same data classification method. This makes the composite suitability map easier to understand and interpret. Suitability map has five class values. While the value of 1 represents that there is no need any new station, the value of 5 indicates that new stations to be built are required. The values varying from 1 to 5 represent the requirements for new stations from low need to high need to be built in the area of interest.

In this assessment, we especially have taken into consideration the service areas of existing fire stations (see Fig. 4c). Every existing fire station with 5-min response times has approximately 2 km radius in this assessment. In composite suitability map, although there are red regions, we do not suggest the new station because of that reason.

In this study, existing 35 fire stations are considered in multicriteria site selection and additional 17 fire stations are suggested in the study area. Fundementals for proposing new fire stations are as follows.

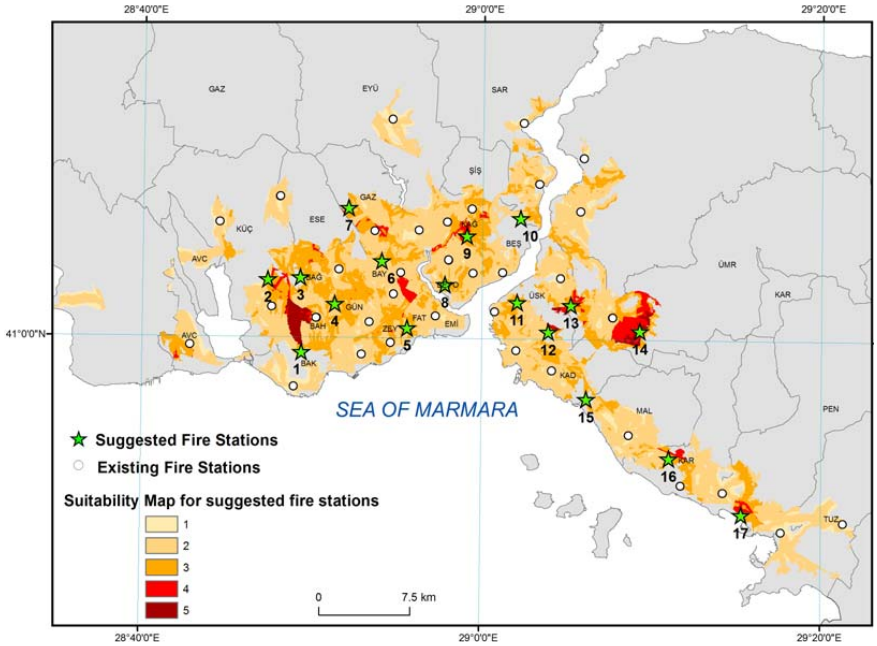

Fig. 5. Suitability map for suggested fire stations.

A new fire station is suggested at the intersection of Bakirköy, Bahçelievler, and Küçükçekmece districts as number 1 in Fig. 5. Station number 1 is required because Bahçelievler district has 19 hazardous material facilities and DHM criterion is the most effective criterion in our analysis. Additional fire station is suggested at the intersection of Bağcilar and Küçükçekmece districts as number 2 in Fig. 5. Station number 2 is proposed because İkitelli quarter of Küçükçekmece district is highly populated and it has hazardous material facilities. A new fire station is also suggested at the Bağcilar district which has highly populated quarters such as Güneşli, Kirazli, and Yenimahalle (number station 3 in Fig. 5). This area is also out of service areas of Kocasinan and Bağcilar stations. Additional fire station is proposed at the intersection of Bağcilar and Güngören districts (number station 4 in Fig. 5). These two districts are highly populated and they need to be protected better from fire threats. Fatih district requires an additional fire station, too (number station 5 in Fig. 5). This district is highly populated and this plays a greater role in our decision. Additional two fire stations are required in the Gaziosmanpşa district (number stations 6 and 7 in Fig. 5). In this decision, high population of Gaziosmanpaşa district plays a greater role. Beyoğlu district also requires a new fire station (number station 8 in Fig. 5). The sea side of this district is out of the service areas of existing Şişli and Beyoğlu stations and it needs to be protected better. Station number 8 is proposed to be built at the seaside for that reason. Kağithane district also requests for a new fire station (number station 9 in Fig. 5). In this decision, very high population of Kağithane district and the high number of hazardous material facilities of Çağlayan district both play an effective role. The quarter of Fatih Sultan Mehmet of Sariyer district also requires an additional fire station (number station 10 in Fig. 5). The population of this quarter has increased in recent years because of internal migration; therefore this quarter and its surrounding areas are needed to be protected better.

Proposing a new fire station to be built is based on being out of service area of existing fire station at the Asian side of Istanbul. New station numbers 11, 12, 13, 14, 15, 16, and 17 are suggested because existing fire stations do not provide for effective fire response in five minutes response time in the study area; and the above mentioned stations are suggested to be built at the Asian side of Istanbul.

6 Conclusions and further suggestions

This study provides decision makers with a model to determine optimal fire station location(s) by combining AHP and GIS. The roles of AHP and GIS in determining optimal locations are explained, criteria for site selection are outlined, and case study results for finding the optimal fire station locations in Istanbul, Turkey are included.

The interaction with AHP and GIS combines decision support methodology with powerful visualization and analyzing capabilities which should considerably facilitate finding optimal locations of fire services and this process improves the decision-making in emergency management.

As a result of all of the performed analyses, existing 35 fire stations are used; and additional 17 new fire stations are proposed according the criteria specified (Fig. 5).

Istanbul is a metropolitan city and it requires to be more accurately protected from potential fire threats.

Determination of the criterion priorities/weights in an accurate, reliable and scientific way is a very important issue in multicriteria site selection decision-making process. In this study 10 academic-related emergency management specialists were the decision makers. In this case, as a suggestion, practitioners or first responders can be used in decision making process and decision making results of academics and practitioners can be compared for future projections.

In the literature, there are very few studies on AHP and GIS interaction for emergency management. We focused on the intersection of these three subjects of AHP, GIS and emergency management. Especially in emergency response, correct analysis is very important and correct criteria and criteria weights need to be determined. In this context, emergencies can be managed in a comprehensive manner, the critical criteria in the model can be determined, the decision making process can be improved by benefiting from the GIS visualization and analysis capabilities, effective use of resources can be achieved more, and human and property loss can be reduced.

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References

Eldrandaly, K., Eldin, N., and Sui, D.: A COM-based Spatial Decision Support System for Industrial Site Selection, Journal of Geographic Information and Decision Analysis, 7(2), 72–92, 2003.

Erden, T.: Fire Brigade Site Selection Based on Geographic Information Systems and Analytic Hierarchy Process: Case Study of Istanbul, Ph.D. dissertation, ITU Institute of Science and Technology, Istanbul, Turkey, 2009.

Erdik, M., Aydinoglu, N., Fahjan, Y., et al.: Earthquake Risk Assessment for Istanbul Metropolitan Area, Earthquake Engineering and Engineering Vibration, 2(1), 1–23, 2003.

Ertugrul, I. and Karakaşoğlu, N.: Comparison of Fuzzy AHP and Fuzzy TOPSIS Methods for Facility Location Selection, Int. J. Adv. Manuf. Tech., 39, 783–795, 2008.

Gay, W. and Siegel, A.: Fire Station Location Analysis: A Comprehensive Planning Approach, ICMA: MIS Report, 1–17, 1987.

Guigin, W., Li, Q., Guoxue, L., and Lüjun, C.: Landfill Site Selection Using Spatial Information Technologies and AHP: A Case Study in Beijing, China, J. Environ. Manage., 90, 2414–2421, 2009.

Habibi, K., Lotfi, S., and Koohsari, M. J.: Spatial Analysis of Urban Fire Station Locations by Integrating AHP Model and IO Logic Using GIS (A Case Study of Zone 6 of Tehran), J. Appl. Sci., 8(19), 3302–3315, 2008.

IMM: Critical Risk Areas and Station Locations, Vol. 7, Istanbul Metropolitan Municipality The study of Fire Safety and Protection, ITU, Istanbul, Turkey, 1989.

IMM: Interim Report, Department of Fire Brigade, http://www.ibb.gov.tr/sites/itfaiye/en-US/Pages/statistics.aspx (last access: 23 February 2010, 2009 (in Turkish).

Jankowski, P.: Integrating Geographic Information Systems and Multicriteria Decision Making Methods, Int. J. Geogr. Inf. Syst., 9(3), 251–273, 1995.

JICA and IMM: The Study on a Disaster Prevention/ Mitigation Basic Plan in Istanbul Including Microzonation in the Republic of Turkey, Final Report, Vol. 5, Istanbul, Turkey, 2002.

Johnston, J.: The Cost Effectiveness of Fire Station Siting and the Impact on Emergency Response, An Applied Research Project, National Fire Academy, 1999.

Jun, C.: Design of an Intelligent Geographic Information System for Multicriteria Site Analysis, URISA Journal, 12(3), 5–17, 2000.

Karaman, H., Scedilahina, M., Elnashaib, A. S., et al.: Earthquake Loss Assessment Features of Maeviz-Istanbul (HAZTURK), J. Earthq. Eng., 12, 175–186, 2008.

Kontos, T. D., Komilis, D. P., and Halvadakis, C. P.: Siting MSW Landfills With a Spatial Multiple Criteria Analysis Methodology, Waste Manage., 25, 818–832, 2005.

Miller, G. A.: The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information, Psychological Review, 101(2), 343–352, 1956.

NFPA 1710: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, National Fire Protection Association, 2001.

Ozcan, H.: Urban Sprawl Prediction in Using Neural Networks, M.Sc. thesis, ITU Institute of Science and Technology. Istanbul, Turkey, 2008.

Petersen, C. E.: 1998 AMES Fire Department Response Time Study. Executive Development, An Applied Research Project,National Fire Academy as part of the Executive Fire Officer Program, submitted, 1998.

Reveshti, M. A. and Heidari, A.: Site Selection Study for Fire Extinguisher Stations Using Network Analysis and AHP Model: A Case Study of City of Zanjan, MapAsia 2007, Kuala Lumpur, Malaysia, 2007.

Saaty, T. L.: The Analytic Hierarchy Process, New York, McGraw-Hill, 1980.

Saaty, T. L.: Group Decision Making and AHP, in: the Analytical Hierarchy Process: Applications and Studies, edited by: Golden, B. L., Wasil, E. A., and Harker, P. T., Berlin: Springer, 59–71, 1989.

Sener, B., Suzen B. L., and Doyuran V.: Landfill Site Selection by Using Geographic Information Systems, Environ. Geol., 49, 376–388, 2006.

Schoppmeyer, J.: Die Wahrnehmung Von Rastern und Die Abstufung Von Tonwertscalen in Der Kartographie, Dissertation, Hohen Landwirtschaftlichen Fakultat der Rheinischen Friedrich-Wilhelms-Universitat zu Bonn, 1978 (in German).

Siddiqui, M. Z., Everett, J. W., and Vieux, B. E.: Landfill Siting Using Geographic Information Systems: A Demonstration, J. Environ. Eng.-ASCE, 122(6), 515–523, 1996.

Yang, J. and Lee, H.: An AHP Decision Model for Facility Location Selection, Facilities, 15(9/10), 241–254, 1997.