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SPATIAL MULTI CRITERIA DECISION MAKING IN FOREST FIRE FIGHTING PLANNING

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ABSTRACT

Multi criteria analyses have been used largely to deal with spatial decision problems since their emergence. Spatial multi criteria analysis is different from conventional multi criteria decision analysis (MCDA) Because it includes geographic component. Two important components of spatial multi criteria decison analysis are Geographical Information Systems (GIS) component and multi criteria decion making (MCDM) component. Many spatial decison problems lead to GIS and MCDA integration. GIS-MCDM integration can be thought of as a process that uses value judgements and then represents results of this judgement spatially on a digital map. Forestry decision problems involve a lot of alternatives and evaluation criteria. Most of the forest management problems are spatial in their nature and usually involve multi-criteria. Fire management is an important component of forest management. In this study the areas that can cope with forest fire effectively are determined according to distance from water resources, distance from streams and distance from settlement areas criteria by using Boolean Analysis and Analytic Hieararchy Process (AHP) for our study area, İzmir Forest Administration Chief Office. Then the results are visualized on a digital map. Besides, the results of the Boolean analysis and AHP analysis are compared.

Keywords: Spatial multi criteria decision making, geographical information systems, analytical hierarchy process, boolean analysis

ORMAN YANGINIYLA MÜCADELENİN PLANLANMASINDA KONUMSAL ÇOK KRİTERLİ KARAR VERME

ÖZET

Çok kriterli analizler ortaya çıkışlarından beri büyük ölçüde konumsal karar problemlerini çözmek için kullanılmışlardır. Konumsal çok kriterli karar analizi, klasik çok kriterli karar analizinden (ÇKKA) farklıdır. Çünkü coğrafi bileşeni içermektedir. Konumsal çok kriterli karar analizinin iki önemli bileşeni, Coğrafi Bilgi Sistemleri (CBS) bileşeni ve çok kriterli karar verme (ÇKKV) bileşenidir. CBS-ÇKKV entegrasyonu, değer yargılarını kullanan ve daha sonra bu yargıların sonuçlarını konumsal olarak sayısal harita üzerinde gösteren bir süreç olarak düşünülebilir. Ormancılıkla ilgili karar problemleri birçok alternatifi ve değerlendirme kriterini içermektedir. Çoğu orman yönetimi problemi yapısal olarak konumsaldır ve genellikle çoklu kriterleri içermektedir. Yangın yönetimi orman yönetiminin önemli bir bileşenidir. Bu çalışmada, su kaynaklarından uzaklık, akarsulardan uzaklık ve yerleşim alanlarından uzaklık kriterlerine gore, çalışma alanı olan İzmir Orman İşletme Şefliği için, Boolean Analizi ve Analitik Hiyerarşi Süreci (AHS) kullanılarak, yangınla etkin olarak mücadele edebilen alanlar gösterilmekte ve sonuçlar sayısal harita üzerinde görselleştirilmektedir. Ayrıca Boolean analizi ile AHS analizinin sonuçları karşılaştırılmaktadır.

Anahtar Kelimeler: Konumsal çok kriterli karar verme, coğrafi bilgi sistemleri, analitik hiyerarşi süreci, boolean analizi

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1. INTRODUCTION

Different problems encountered in life can be thought of as a multi criteria decision making problems. As stated by Vassilev et al. (2005), multi criteria decision making problems can be divided into two distinct classes. In the first class of problems a finite number of alternatives are explicitly given in a tabular form. These problems are called discrete multi criteria decision making problem or multi criteria analysis problems. In the second class a finite number of explicit set of constraints in the form of functions define an infinite number of feasible alternatives. These problems are called continuous multi criteria decision making problem or multi criteria optimization problems. The techniques used in the different approaches of decision analysis are called multi criteria decision methods (MCDM).

Geographical Information Systems (GIS) provide forest managers with tools to use to plan forest operations by allowing them to visualize and integrate data into the planning decisions. As forest planning process becomes increasingly complicated, there is a need for assisting forest planners with operative tools. The combined use of GIS and MCDM allows forest managers to visualize solutions proposed by MCDM and to have a better understanding of the problem they confront.

The main purpose of this study is to show forest managers how GIS and MCDM can facilitate fire fighting planning decisions and to show how results of this study can be used as a decision tool in forest fire fighting planning. For this purpose the integrated use of GIS- Boolean Analysis and GIS-Analytic Hierarchy Process (AHP) are shown as a prototype application. The effective/ineffective areas in forest fire fighting are determined by using GIS- Boolean Analysis and GIS-AHP.

This study focuses on fire fighting planning from the strategic planning perspective by taking into account distance from water resources, distance from streams and distance from settlement areas criteria. It is very important to determine the effective/ineffective areas in fire fighting so that allocation of fire fighters can be made more accurately and more emphasize can be given to the ineffective areas. By visualizing the effective/ineffective areas, it is considered that fire fighting planning activities and allocations of resources can be managed more accurately. It will be possible to take proactive measures and transfer resources to the ineffective areas according to results of analyses represented on a digital map. The results of this study can serve as a decision tool in allocating fire fighters and resources. It is important to notice that the findings of this study may change when other criteria of struggling with forest fire are added to the analyses.

In the application part, the problem is handled as a spatial multi criteria decision making problem. There are several criteria that must be considered in evaluating the effectiveness/ineffectiveness of the study area in struggling with forest fire, such as fuel/vegetation type, soil properties, topographical information, slope, aspect and altitude information of the study area, distance from water resources, distance from settlement areas, distance from streams and distance from roads. However, in this study only distance from water resources, distance from streams and distance from settlement areas criteria were used. Because the maps of the other criteria were absent and unavailable to authors, and only maps of these three criteria could be constituted with the data obtained from the study area. The most important point in using GIS, Boolean analysis and AHP is the availability of maps of all criteria.

2. MULTI CRITERIA DECISION MAKING

Pairwise comparisons, ranking method and rating methods are some of the methodologies used in multi criteria decision making. Pairwise comparison technique is based on the method called the AHP, a decision making technique developed by mathematician Thomas L Saaty. It is an Eigenvalue approach to the pairwise comparisons and based on building hierarchy of criteria and at each node of hierarchy weighting is performed (Saaty, 1980; 1986).

The AHP consists of three main operations: hierarchy construction, priority analysis, and consistency verification. The decision makers need to break down complex multiple criteria decision problems into their component parts. This approach allows the decision maker to structure problems in the form of a hierarchy.

Figure 1 shows the basic hierarchy structure in AHP(Felek et al., 2007).

After the hierarchy structuring, the decision makers have to compare each element in the same level in a pairwise fashion (Ho, 2008; Liberatore and Nydick, 2008).

Some key and basic steps involved in this methodology are as follows (Saaty, 1980; Vaidya and Kumar, 2006):

1. Stating the problem.
2. Broadening the objectives of the problem or considering all factors, objectives and their outcomes.
3. Identifying the criteria of the problem.
4. Structuring the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.
5. Comparing each element (pairwise comparisons) in the corresponding level and calibrating them on the numerical scale. The scale has values range from 1 to 9 (Üstün et. al., 2005) as shown in Table 1 (Saaty, 1980).
6. Performing calculations to find the maximum eigenvalue (λ), consistency index (CI), consistency ratio (CR), and normalized values for each criteria/alternative. λ represents average value of the consistency vector, CI provides a measure of departure from consistency, CI and CR are calculated as shown in Formula 1 and Formula 2, respectively:

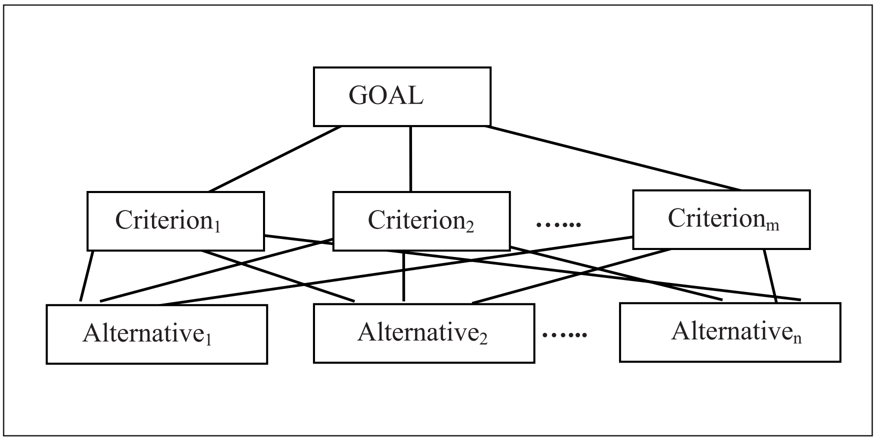

Figure 1. The Basic Hierarchy Structure in AHP

Table 1. Scale for Pairwise Comparisons

Intensity of importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

$$CI = (\lambda_{max} - n) / (n-1) \quad (1)$$

$$CR = CI / RI \quad (2)$$

RI is the random index and depends on the number of elements being compared as shown in Table 2 (Saaty, 1980; Özdemir, 2002):

Table 2. Random Inconsistency Indices (RI) for n=1, 2, ..., 15

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

If $CR < 0.10$, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if $CR \geq 0.10$, the values of the ratio indicates inconsistent judgements.

7. If the maximum Eigen value, CI, and CR are satisfactory then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range.

Boolean analysis is also used in multi criteria decision making problem and is used only when two states are possible (criterion satisfied and criterion not satisfied). This analysis was developed by George Boole, who devised rules and methodologies for combining two-states variables. In boolean search it is generally concerned with the AND operator. The logical AND operator produces a true result from the phrase "A AND B" only if A and B are "true". In GIS, this methodology is used in a multiplication overlay between layers containing only zeroes (representing areas where conditions are "false" or "criterion is not satisfied") and ones (representing areas where conditions are "true" or "criterion is satisfied") (Eastman, 2003).

Boolean analysis is used to combine series of input map layers into a single output layer through use of and, or and not operators. In Boolean approach, all criteria are assesed by thresholds of suitability to produce Boolean maps, which are then combined by logical operators such as intersection (AND) and union (OR) (Jiang and Eastman, 2000).

3. FOREST MANAGEMENT

Forest management is the process of organizing a collection of forest stands so that they produce the resources that the landowner wants from that forest. Common goals for forest management are to produce the resources demanded by the landowner and society to maintain a sustainable supply of resources over time and to minimize conflicting demands in resource use. Management typically begins with forest management plan that identifies the objectives of the landowner, outlines the treatments and timetables required for each stand (Young and Giese, 2003).

Forest management includes management of harvesting and recreational areas, protection of endangered species and archaeological sites. Management of forest resources is a complex task due to multi-functional nature of these resources Therefore, forest management and planning problems usually involve decisions, which have to be made in the presence of multiple objectives. (Aronoff, 1995; Kazana et al., 2003; Mohren, 2003).

Forest management consists of several subsystems and fire management system is one of these systems. It is very important to minimize damage caused by forest fire. This can be achieved by developing an efficient fire management system. In the literature fire management is handled from two perspectives; to extinguish fire (fire fighting planning) and to predict fire spread. Fire fighting planning is an important component of fire management system.

Martell (1982), reviewed OR approaches in forest fire management comprehensively. Hirsch and Martell (1996) reviewed initial attack fire crew productivity and effectiveness, Martell et al. (1998) handled forest management challenges for operational researchers, Dimopoulou and Giannikos (2001), discussed spatial optimization of resource deployment for forest fire management. By detecting and attacking fires soon after they are reported or by controlling escaped fires effectively it is possible to minimize of negative impact of forest fires. Forest fire management has seen the development of several analytic methodologies, based on operational research techniques (Dimopoulou and Giannikos, 2004).

During the last few years, the forest fire management policy is mainly based on geographical information systems which provide efficient spatial data storage and retrieval, handling, integrating and synthesizing of socio-economic as well as ecological data. Salazar (1990), used GIS in assigning fire management analysis zones, Zack and Minnich (1991), discussed integration of GIS with a wind field model for fire management. Vertinsky et al. (1994), used GIS based system approach in forest management. Bilgili et al. (2001), discussed the role of GIS in fire danger rating and fire management planning. Küçük et al. (2005), discussed importance of fuel type, crown and surface fuel loading, and distribution of fuel types for determination of fire potential, fire damages and costs using GIS. Küçük and Bilgili (2006), developed fire behavior maps using GIS in order to facilitate decision making process of fire organizations for enabling them making reliable decisions. Küçük and Bilgili (2007), mapped fire behavior using GIS for Korudağ.

The forest database design is crucial in a forest management. The data should be accurate, properly organized, detailed and it should be obtained easily. The gathering of spatial and nonspatial data and analyzing them determine the quality of forest management.

Increasing amounts of scientific information is important to support the ongoing goals and objectives in managing forests. One goal is to adapt forest management continually to accept new objectives. One goal is to learn how to manage forests sustainably so benefits continue and without compromising the needs of future generations. Another goal is to acquire knowledge about the current state of the forest and about how management and natural processes affect future outcomes. These goals require obtaining the new new data and insights through development and deployment of new information technologies, including geographical information systems (Franklin, 2001).

The amount of data and information involved in the forest management process is often overwhelming. Integrated decision support systems help forest managers to make consistently good decisions about forest ecosystem management (Potter et al., 2000). Compared to previous forest management approaches, new forest management strategies require integration of spatial information technologies, such as GIS, remote sensing, and decision support systems (Franklin, 2001). As Stated by Næsset (1997), GIS has the ability to answer geographical questions, based on the information in digital maps with associated attribute databases. Thus the most important point in GIS is digital map database.

Figure 2 summarizes the role of GIS in management of fire fighting planning.

For the fire management system to function properly a comprehensive database must be designed regarding the data mentioned in Figure 2. GIS associates spatial and nonspatial database with digital maps. By designing GIS based database all information regarding fire and how attacking this fire can be queried by using functions of GIS. Reservoir, fire tower and pool location, crew and equipment (helicopter, airplane, water tank) information, communication devices information are components of fire fighting planning. Detecting coordinate of fire has a strategic role in fire fighting planning. Forest road map is necessary if fire can be controlled by using highway. This map has a crucial role in determining road status (main road, secondary road), road type, slope and aspect information must be included in the topography. By using query function or info tool of GIS forest road details can be learned. In allocating vehicle to fire location it is important to know whether the road is steep or not, and thereby sending vehicle that has appropriate feature according to topography. Vehicle feature data can be get from crew, vehicle and equipment data menu. It is also essential to know if there is inaccessible parts of the road network. Stream

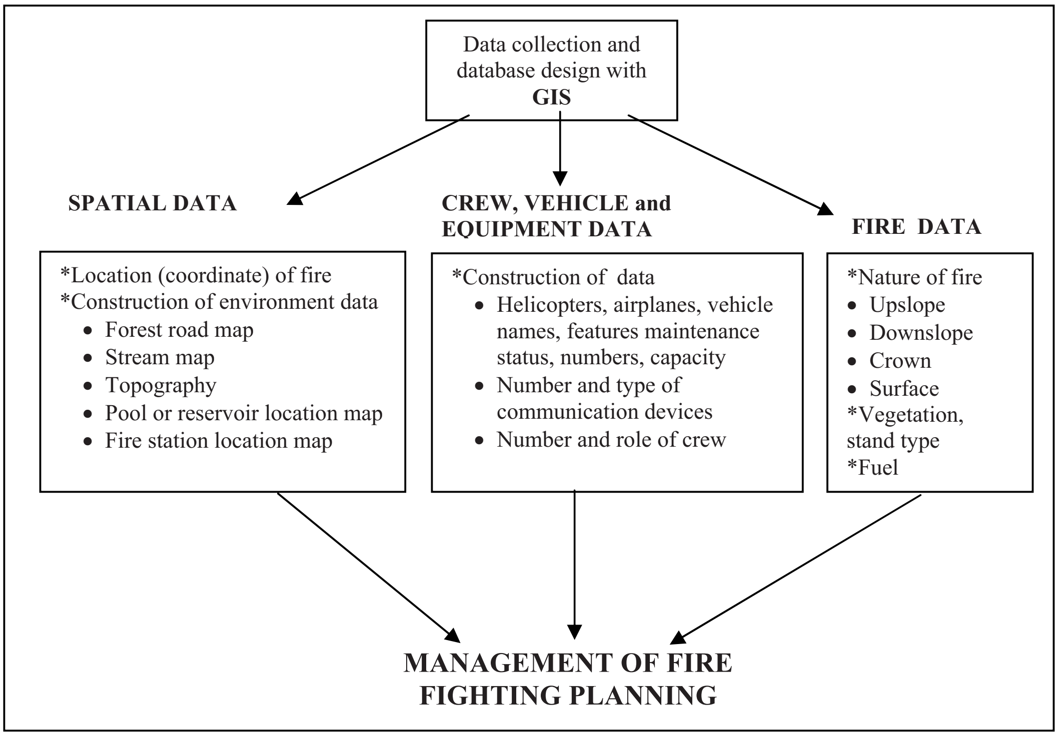

Figure 2. Management of Fire Fighting Planning by Using GIS

map, pool location or reservoir map is important in determining where the nearest water resources are. Of course fire type (upslope, downslope, crown or surface) is very important in deciding fighting form with fire. Decision making is significant part of this management process. Hierarchy of decisions, that is, who decides for what, decisions related to explication of spatial data, decisions concerning fire management policy has an important role in fire fighting planning. GIS supplies the all needed information in the most efficient and the quickest way.

4. GIS AND MULTI CRITERIA DECISION MAKING INTEGRATION

Environmental management has been a main motivator of developments in GIS. When these systems were first developed in the early 1960s, they were no more than a set of innovative computer-based applications for map data processing. But GIS grew very fast and became an important element of information technology (Franklin, 2001; Lo and Yeung, 2002). As stated by Kleynhans et al. (1999), the development of GIS technology makes it possible to compile, store, retrieve, analyse and display vast quantities of spatial data. While the use of GIS is expanding day by day, its most important applications include those that support decision making. GIS technology offers combined power of both geography and the information systems and provides ideal solutions for effective natural resource management (Shamsi, 2005).

Multi criteria analyses have been used largely to deal with spatial decision problems since their emergence. The first works including GIS-multi criteria analysis integration were in the late 1980s and the early 1990s (Chakhar and Martel, 2003).

Spatial multi criteria analysis is different from conventional multi criteria decision analysis (MCDA). Spatial multi criteria analysis requires information on criterion values and the geographical locations of alternatives and the results of analysis depend not only on the geographical distribution of attributes, but also on the value judgements of decision maker (Jankowski, 1995; Malczewski and Ogryczak, 1996). As stated by Carver (1991) and Jankowski (1995), two important components of spatial multi criteria decison analysis are GIS component and multi criteria decision making component.

Multi-criteria evaluation (MCE) and multi criteria decision making are very important concepts in GIS. Many spatial decison problems lead to GIS and multi MCDA integration. These two disciplines can benefit from each other. On the one hand, GIS techniques have an important role in analyzing decision problems and it is a decision support system that integrates spatially referenced data into a problem solving environment. On the other hand, MCDA provides many techniques and procedures for structuring decision problems, evaluating and prioritizing alternative decisions. GIS-multi criteria decision making integration can be thought of as a process that transforms and combines geographical data and value judgements of the decision maker to obtain information for decision making (Malczewski, 2006).

5. MATERIALS AND METHODS

In this study GIS and multi criteria decision making integration was applied for Izmir Forest Administration Chief Office located in western Turkey. Izmir Forest Administration Chief Office is subordinate to Izmir Directorate of Forest Administration. This institution is divided into eleven forest administration offices, and our study area is one of them.

This study is performed to initiate contemporary forest management planning, which is different from conventional forest management planning, in the study area. Generally forests are not managed according to contemporary forest management perspective in the study area. Most of the forest administration chief offices have paper maps and do not develop forestry database regularly. In contemporary forest management forest database must be designed regularly and all maps must be in digital form. It is important to handle forestry problems by using spatial information systems. GIS provides not only organization and management of data but also integrates different optimization models, such as, Operations Research (OR), into the problem solving environment. GIS is valuable in transition from conventional forest management to the contemporary forest management. In this paper a prototype study that integrated GIS and OR was presented.

There are several criteria that must be considered in fire fighting planning process, such as fuel/ vegetation type, soil properties, topographical information, slope, aspect and altitude information of the study area, distance from water resources, distance from settlement areas, distance from streams and distance from roads. However, in this study only distance from water resources, distance from streams and distance from settlement areas criteria were used. Because the maps of the other criteria were absent and only maps of these three criteria could be constituted with the data obtained from the study area. The most important point in using GIS, Boolean analysis and AHP is the availability of maps of all criteria.

First phase of the application is forest database design and transformation of the water resources, streams and settlement areas maps into the vector based digital maps. The raw data were obtained from Izmir Forest Administration Chief Office. Water resources were available only as coordinate information. All water resources were geocoded. Stream map and settlement area map were transformed into the digital maps. Following this, all vector based maps were converted to the raster based maps. This conversion was necessary to perform Boolean analysis and AHP module in IDRISI software package. Pairwise comparisons matrix was constituted by interviewing with the directorates of fire combatting department of Izmir Forest Administration Chief Office. IDRISI software package was used for all analyses.

6.RESULTS

In this section,GIS-Boolean analysis and GIS-AHP analysis were done and the results of analyses were compared.

6.1 Boolean Analysis

In order to do Boolean analysis, firstly all criteria were standardized to Boolean values (0 and 1). Factors (criteria) of our study were distance from water resorces factor, distance from streams factor and distance from settlement areas factor.

6.1.1 Distance from Water Resources Factor, Streams Factor and Settlement Areas Factor

Water resources and streams are strategic components in fire management. The areas closer to the water resources and streams are considered to be more suitable (effective) in coping with forest fire than the areas that are distant from water resources and streams. Settlement areas are important factors to intervene and control fire. However, according to different points of view settlement areas can also be considered as a risky factor. In some cases, the areas closer to the settlement areas are more fire prone because of the human factor.

In this study the areas closer to the water resources, streams and settlement areas were considered as suitable (effective) (1) and the others were considered as not suitable (ineffective) (0).

There are four water resources in our study area named as Buca Gölet, Kaynaklar Göleti, Sarnıç Göleti and BP Olduruk. Water resources map was derived by rasterizing and using the module DISTANCE in IDRISI software package. Then distance image, which showed a simple linear distance from all water resources in our study area, was obtained as shown in Figure 3.

In this stage it was needed to RECLASSIFY continuos image of distance from water resources to determine the distances that are suitable and the distances that are not suitable. As interviewed with the head of fire department of İzmir Forest Administration Chief Office, the areas that have a distance less than 5000 meters to the water resources

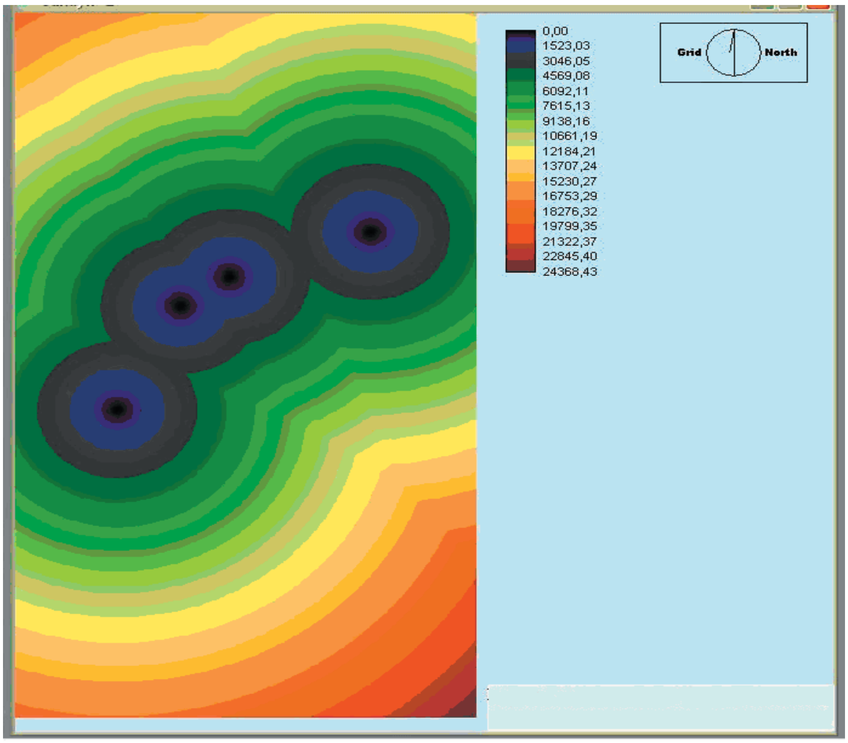

Figure 3. Distance Map of the Water Resources

were considered as suitable (1) and those equal to or beyond 5000 meters were considered as not suitable (0). Reclassification process and reclassed distance map of the water resources were shown in Figure 4 and Figure 5, respectively.

The same procedures were followed for the distance from streams factor and the distance from settlement areas factor. For reclassification of distance from streams factor, areas that have a distance less than 5000 meters to the streams were considered as suitable (1) and those equal to or beyond 5000 meters were considered as not suitable (0). For reclassification of the distance from settlement areas factor, areas that have a distance less than 2000 meters to the settlement areas were considered as suitable (1) for effectively struggling with the fire and those equal to or beyond 2000 meters were considered as not suitable (0). Figure 6 and Figure 7 showed reclassed distance map of the streams and reclassed distance map of the settlement areas, respectively.

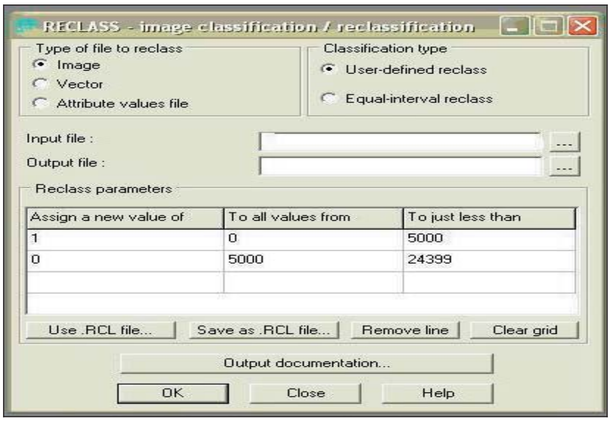

Figure 4. Reclassification of Distance Map of the Water Resources

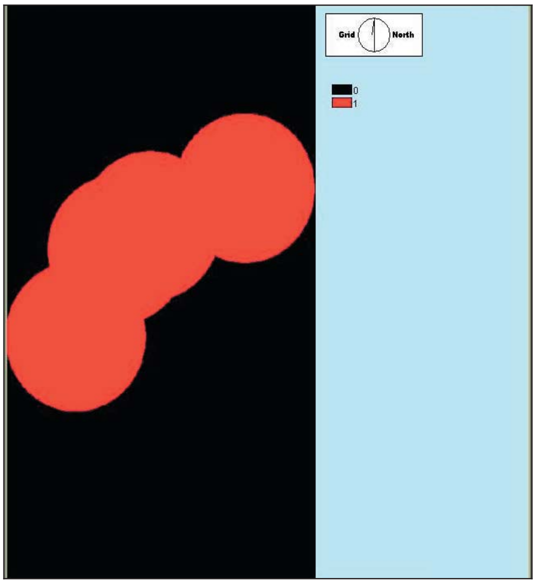

Figure 5. Reclassed Distance Map of the Water Resources

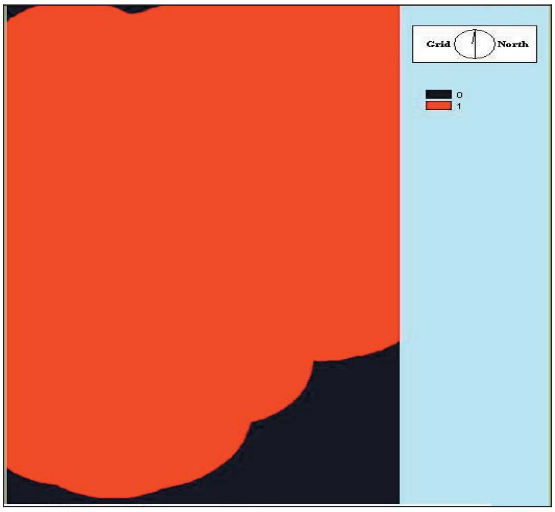

Figure 6. Reclassed Distance Map of the Streams

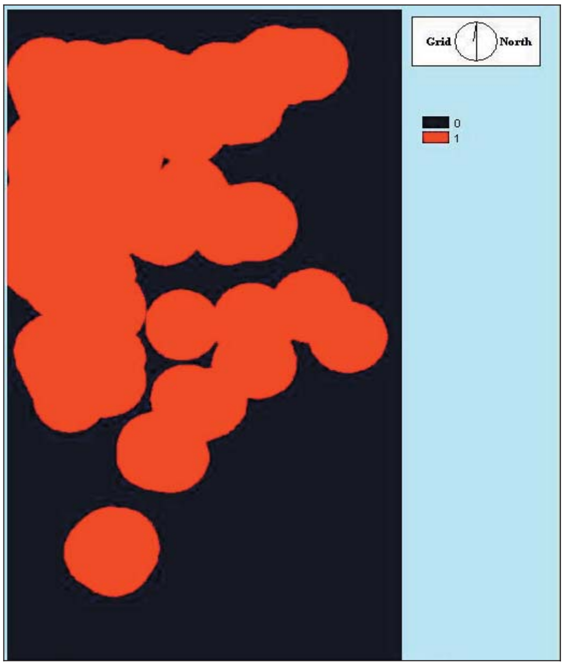

Figure 7. Reclassed Distance Map of the Settlement Areas

6.1.2 Boolean Aggregation of Factors

All factors have been transformed into Boolean images and they were ready to be aggregated. All of these three factors were multiplied together to produce a single image of suitable areas that can effectively cope with the forest fire. This aggregation process was done by using image calculator with the AND operation in IDRISI software package as shown in Figure 8.

At the end of boolean analysis, the most suitable areas that can cope with forest fire according to defined set of criteria were determined as shown in Figure 9.

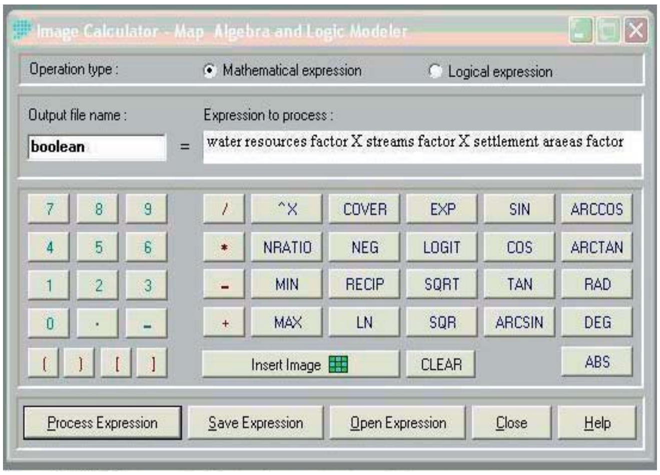

Figure 8. Multiplication of All Factors by Using Image Calculator

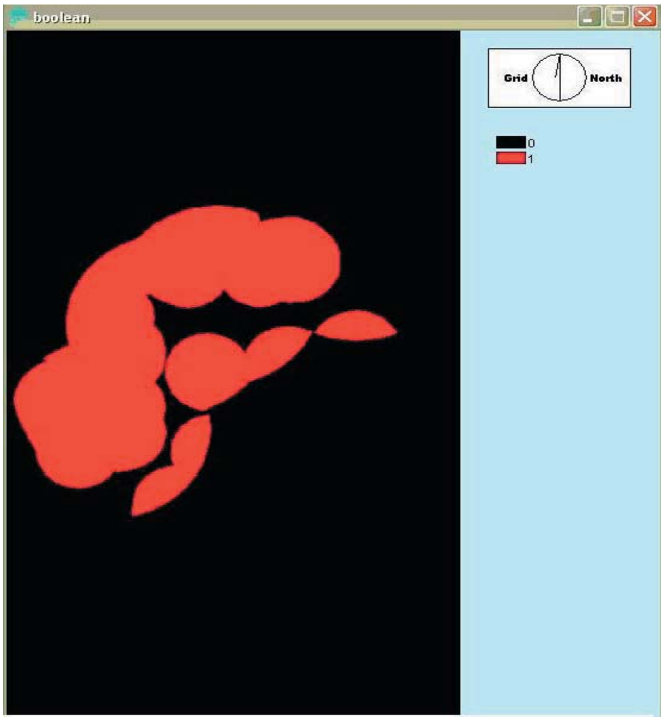

Figure 9. The Most Suitable Areas that can Cope with Forest Fires Effectively According to Boolean Analysis

As it is seen from the Figure 9 that, Boolean analysis is helpful in determining effective and ineffective areas in struggling with forest fire according to predetermined set of criteria. However this analysis can not give a detailed information about for example distance of one area to (all criteria) water resources, streams and settlement areas simultaneously. For this purpose in the following section AHP analysis was performed to obtain more detailed information.

6.2 Analytic Hierarchy Process and Fuzzy Standardization of Factors

In order to perform AHP in IDRISI, fuzzy standardization of all factors (distance from water resources, distance from streams and distance from settlement areas) must be done. The factors are not just reclassified into 0 and 1, but are rescaled to a particular common range according to some function by fuzzy standardization. In order to use fuzzy factors with the multi criteria evaluation, these factors are standardized to the byte level range of 0-255. The suitability increases as the areas get closer to the value of 255, i.e., the areas that has same colour with the number of 255 are said to be more effective in fire fighting than other areas on the same map. In fuzzy standardization process, distance maps of the water resources, streams and settlement areas are used.

Distance from water resources factor was rescaled to the byte range of 0-255 by constituting fuzzy standardized distance map of water resources. Prior to fuzzy standardized distance map fuzzy standardization must be done. In this process the areas that have a distance less than 5000 meters to the water resources were considered as suitable (1) and those equal to or beyond 5000 meters were considered as not suitable (0). As it was shown in Figure 10, the suitability decreased when the distance increased. For this reason monotonically decreasing menu was selected in the fuzzy standardization process. Figure 11 shows fuzzy standardized distance map of water resources.

In the fuzzy standardization process of the streams and the settlement areas, also monotonically decreasing menu was selected. Figure 12 and Figure 13 show fuzzy standardized distance map of streams and settlement areas, respectively.

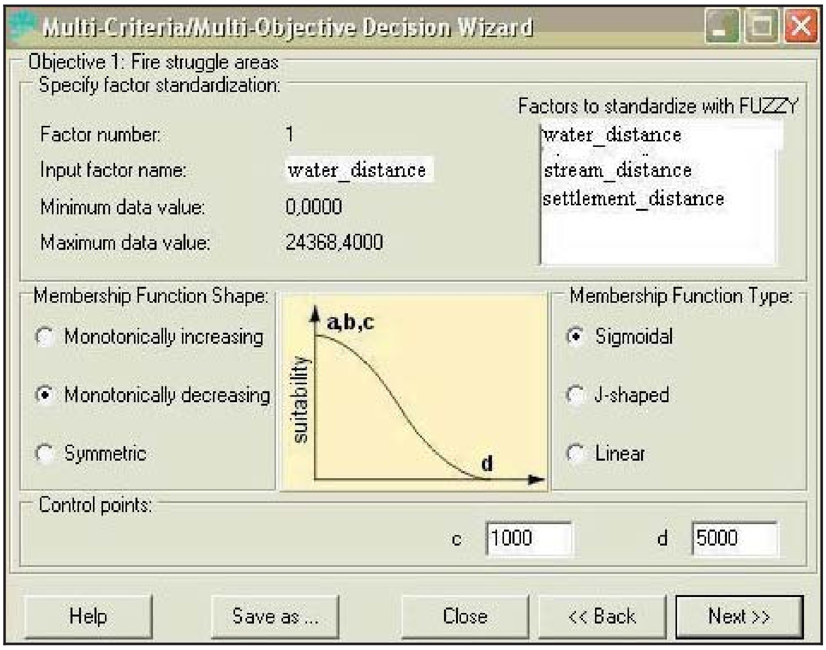

Figure 10. Fuzzy Standardization Process for Distance Map of Water Resources

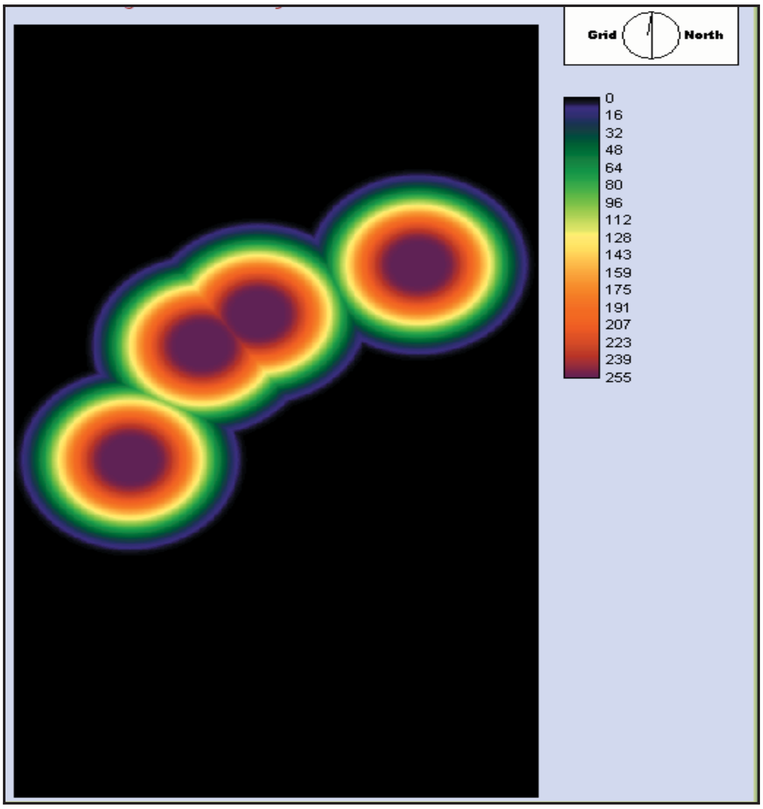

Figure 11. Fuzzy Standardized Distance Map of Water Resources

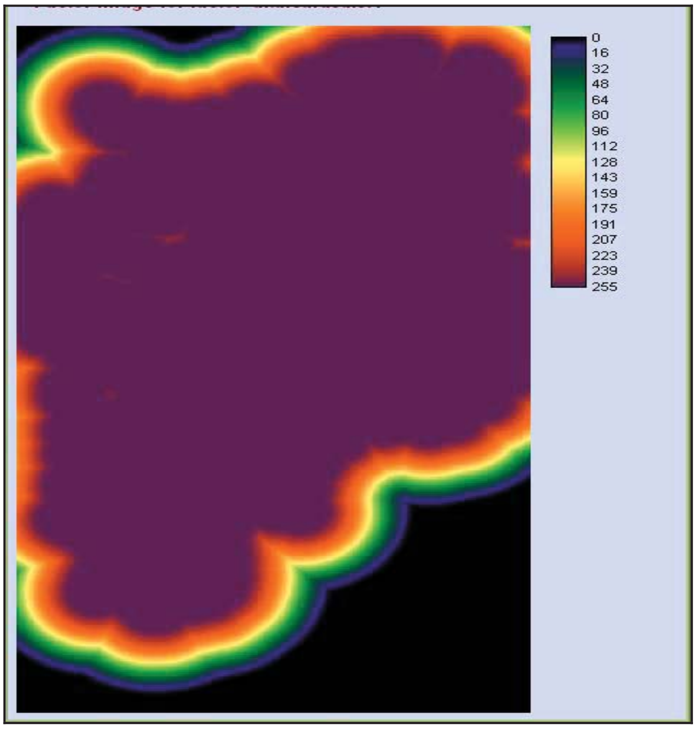

Figure 12. Fuzzy Standardized Distance Map of Streams

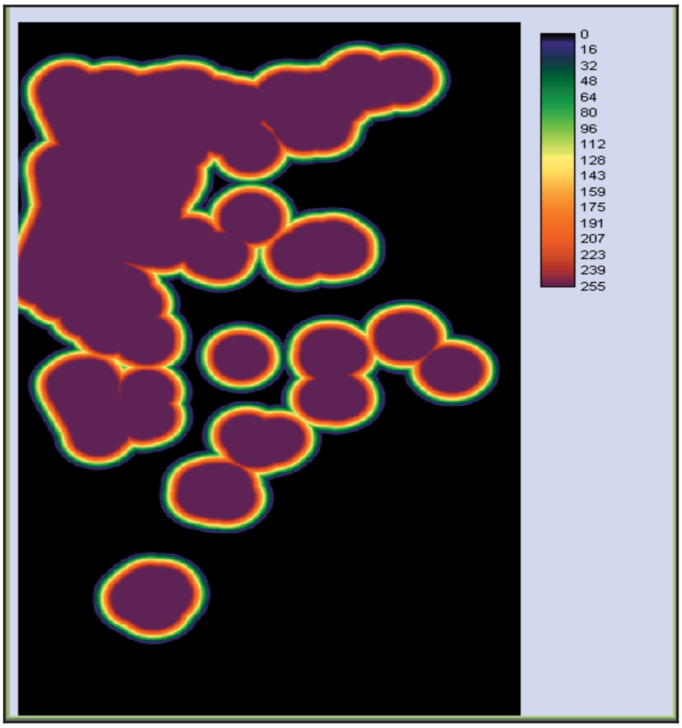

Figure 13. Fuzzy Standardized Distance Map of Settlement Areas

6.2.1 Pairwise Comparisons

Following fuzzy standardization of factors, pairwise comparison matrix was by interviewing the personel and the head of fire department. Figure 14 shows pairwise comparisons matrix.

Eigenvectors of weights were found as 0.0877 for water resources, 0.7732 for streams and 0.1391 for settlement areas. These weights show that streams are the most important factor in fire fighting planning in this study. That is, the proximity to the streams determines the effectiveness of the study area in fire fighting planning. The second important factor in determining the effectiveness of the study area is its

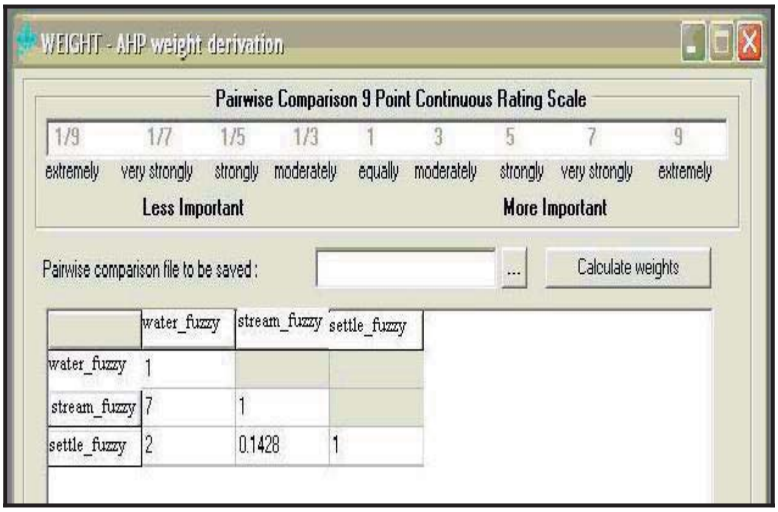

Figure 14. Pairwise Comparisons Matrix

proximity to the settlement areas. Water resources are found to be the least important factor in determining the effectiveness of the study area in fire fighting planning. Consistency ratio was found as 0.05 and was acceptable for this study.

All of the fuzzy standardized distance map of the factors were multiplied with their weights by using image calculator function of the IDRISI software package. Figure 15 represents this process. Figure 16 shows the result of this multiplication, that is, the most

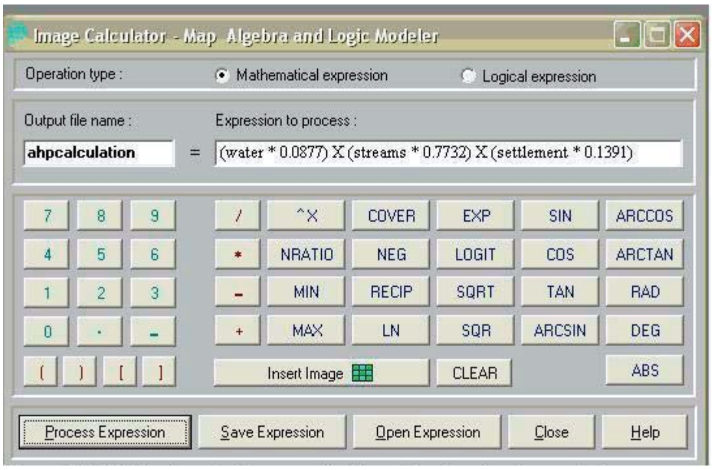

Figure 15. Multiplication of All Factors by Their Fuzzy Standardized Distance Maps

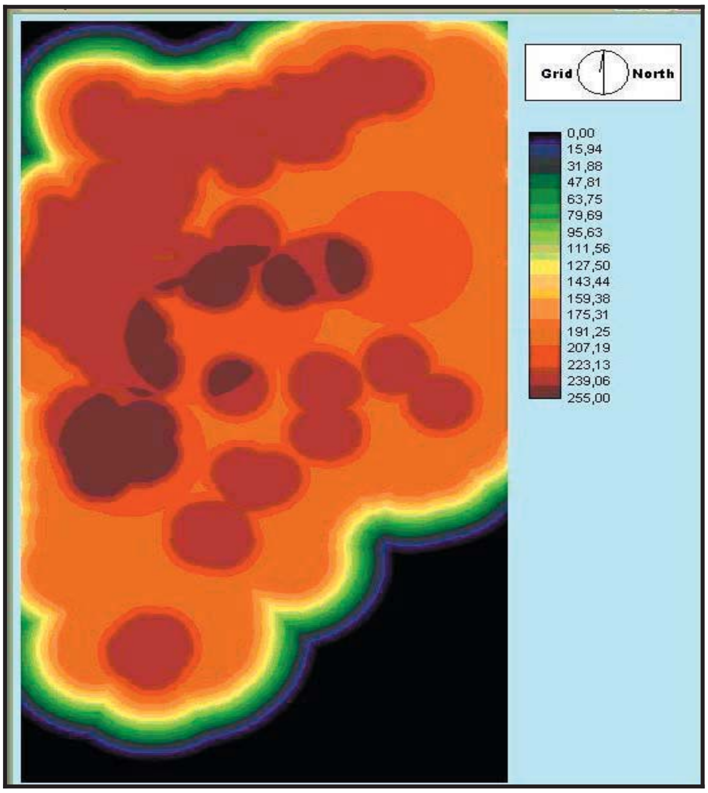

Figure 16. The Most Suitable (Effective) Areas that can Cope with Forest Fires According to AHP

suitable (effective) and not suitable (ineffective) areas in coping with forest fires according to AHP.

Figure 17 shows the effective/ineffective areas found in this study in a more detailed way. The marked regions show the areas that has the same colour with the number 255. These areas represent the intersection of the areas where the conditions of the most streams, the most settlement areas and the most water resources are met simultaneously.

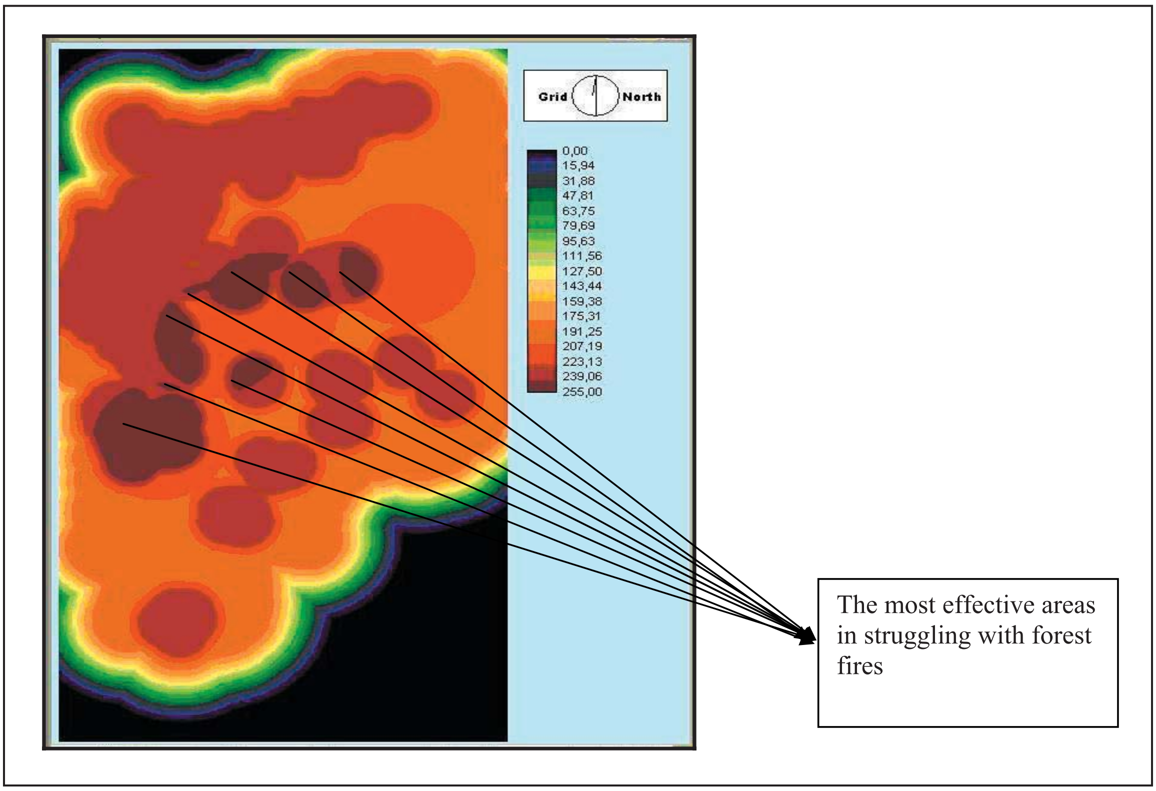

Figure 17. Representation of the Most Effective Areas in a more Detailed Way

7. CONCLUSIONS

In this study both boolean analysis and AHP was used to determine the most suitable (effective) areas that can cope with the forest fires according to defined set of criteria and it is discussed whether to use boolean approach or AHP. Boolean analysis is used when only two states are possible (criterion satisfied and criterion not satisfied). However, in many problems decision making process can be more sophisticated. There may be situations in which boolean analysis does not work effectively. Boolean analysis requires that all of the criteria have equal importance in the solution. But there may be situations in which some criteria are more important than the other criteria. In this case, some other techniques which take into account value judgement of decision maker, such as Analytic Hierarchy Process-GIS integration, must be used. Results of AHP-GIS integration are more comprehensive and give more information than the results of boolean-GIS integration as shown in this study.

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