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EARTHQUAKE HAZARD ANALYSIS FOR DISTRICTS OF DÜZCE VIA AHP AND FUZZY LOGIC METHODS

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Earthquake hazard is defined as the determination of a ground motion from a large earthquake that can cause damage and loss in a certain place and within a certain time period. Damage due to an earthquake is an important element of the earthquake risk concept, which is defined as the probability of loss of property and life. There are many variables that constitute the earthquake hazard. The number and type of these variables may vary in different studies and for different purposes. In this study; geology of the city, lengths of active faults and the epicenter of the earthquake outer-center points of the earthquakes with a magnitude greater than 3 on between 1905 and 2016 were used. In this study; Open Source Code Geographic Information Systems (GIS) Software QGIS, Analytical Hierarchy Process (AHP) and Fuzzy Logic Method have been used to investigate the earthquake hazard of Düzce districts. These parameters were evaluated together to create thematic maps. Regions were determined in terms of earthquake hazard in the generated maps. As a result of the analysis by two methods, the districts showed similar results in terms of earthquake hazard. According to the three criteria evaluated, the central district is the most risky district with 39%. Yigilca, Gölyaka and Kaynaslı districts are medium risky districts. Cilimli, Gümüsova, Cumayeri and Akcakoca are the least risky districts.

Index Terms — Düzce, earthquake hazard analysis, AHP, fuzzy logic, open source code geographic information systems, QGIS, spatial operations

I. INTRODUCTION

93% of our country's soil, 98% of its population and 93% of its dams [1] are in earthquake-affected areas, so the social and economic losses caused by earthquake disaster require very serious precautions [2]. Estimates based on probability calculations in earthquake hazards determinations are important decision tools since the location, timing, magnitude and other features of future earthquakes are uncertain [3].

Earthquake hazard analysis of the settlements is required for taking the precautions. Analyzes should be made using geographic information systems (GIS). Thus, with the thematic maps created together with the spatial and attribute data, scenarios related to pre-disaster, disaster moment and post-disaster can be established with the disaster that can occur. In this context, as a result of the analyzes carried out together with the geographic information systems, priority districts can be determined according to the hazard value. Before any disasters occur, it is possible to achieve the least loss of life and property at the time of disaster and afterwards by carrying out studies aimed at high risk dangerous districts. Geographic information systems can be used to determine the most suitable places for collection areas after disaster.

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II. MATERIALS AND METHODS

The study area includes districts of Düzce. Düzce is plainly located in the western black sea region. The province center of Düzce with an area of 2492 km2 is located at 39051 minutes north latitude and 31008 minutes east longitude. The place of Turkey among the illusions lies in the western and northern part of the Bolu province lands to the east of Sakarya province and the southwestern part of Zonguldak province [4]. The study was conducted in five steps. In the first step, spatial data were used to use in earthquake hazard analysis and to create thematic map in geographic information system. At this step, Düzce provincial boundaries and district boundaries were manually digitized in the form of closed area (polygon) using QGIS open source geographical information system and Google Hybrid map as a base layer. Later active faults and alluvial areas were digitized using the WMS (Web Map Service) published by the General Directorate of Mineral Research and Exploration, "Geoscience Map Viewer and Drawing Editor " [5], as a base layer on QGIS [6]. The epicenter points of earthquakes were obtained by searching the magnitude is greater than or equal 3 through the web page of "B.U. KOERI-RETMC Earthquake Catalog Search System" [7] of Boğaziçi University, Kandilli Observatory and Earthquake Research Institute. The epicenter, which is the earthquake center point, is the point on the earth closest to the focus point. At the same time, it is the point where the earthquake is most damaged or felt the strongest [1]. In the second step, spatial intersection operations were performed using vectorized alluvial areas, active faults, earthquake epicenter point data with Düzce district boundaries using QGIS. Alluvial areas, active faults and earthquake point amounts within the boundaries of each district are thus determined for analysis. In the third step, alluvial areas, active faults and earthquake point data obtained for each district were used as parameters and analyzed with AHP. In the fourth step, alluvial areas, active faults lengths and count of earthquake epicenter point data obtained for each district are used as parameters and analyzed with MATLAB Fuzzy Logic Designer add-on [8]. In the fifth step, based on the earthquake hazard results obtained, thematic maps have been created based on the districts.

A. Preparation of Spatial Data

In the preparation step of spatial data, firstly the province boundaries and districts of Düzce are created by QGIS in the form of vector layer (Figure 1). Afterwards all the vector layers shown in Figure 2 were created. These layers are alluvial areas, active faults and epicenter of the earthquake outer-center points of the earthquakes with a magnitude greater than 3 on between 1905 and 2016.

Fig.1. Creation of Vector Layers with Düzce Province and District Boundaries with QGIS.

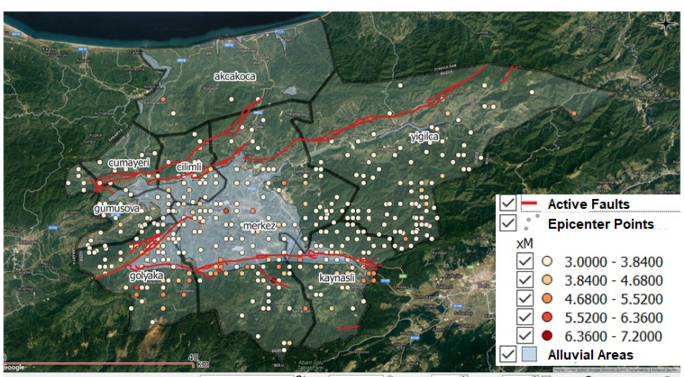

Fig.2. Demonstration of vector layers of epicenter points, active faults and alluvial areas by QGIS for Düzce Earthquake Hazard analysis.

B. Creation of Spatial Data on the Basis of Districts

The layers created in the vector format are intercepted in the QGIS to determine the quantities within each of the boundaries of each district. As a result, new vector layers were created.

C. Earthquake Hazard Analysis with Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was originally proposed by Myers and Alpert in 1968, and in 1977 it was developed as a model by Saaty to be used in the solution of decision making problems [9]. AHP can be described as a decision-making and forecasting method that gives the percentage distributions of decision points in terms of the factors affecting the decision, which can be used if the decision hierarchy can be defined. The AHP relies on individual benchmarks on a decision hierarchy, using a pre-defined comparison scale, in terms of the factors that influence decision making and, if necessary, the significance of decision points in terms of these factors. As a result, differences in importance are transformed into percentages on decision points [10]. As shown in Figure 3, firstly an aim is determined with the AHP and the criteria are determined accordingly. Subsequently, for each criterion, alternative values are used to obtain values for each alternative. As a criterion epicenter of the earthquake outer-center points of the earthquakes with a magnitude greater than 3, active faults lengths and alluvial areas were used for each district boundary to determine the earthquake hazard. Alternatively, the districts are used. Thus, appropriate earthquake hazard results were obtained by using the values of the three criteria each ruler had. The values used for each district in the AHP analysis are shown in Table I. The values obtained as the result of the analysis are shown in Table II. As a result of the analysis, it is seen that the central district has the highest earthquake hazard value.

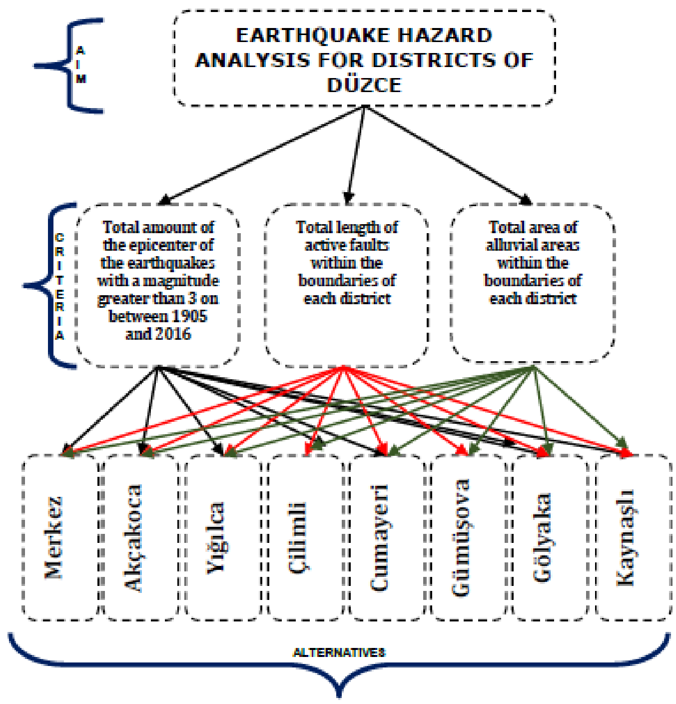

Fig 3. General Structure of AHP.

Table I. Epicenter of the earthquakes with a magnitude greater than 3, active faults lengths and alluvial areas were used for each district boundary values

Districts	Epicenters >= 3 (total)	Active Faults (m)	Alluvial Areas (km²)
Akçakoca	4	6593	24.020
Yığılca	96	66661	7.445
Çilimli	24	27619	46.401
Cumayeri	14	22855	10.983
Gümüşova	33	8575	24.842
Gölyaka	72	46472	46.664
Kaynaşlı	68	32143	47.294
Merkez	142	80405	323.785

Table II. Earthquake Hazard Values of Düzce Districts as a Result of Analysis with AHP

District	Rank	AHP Values (%)
Merkez	1	39.55
Yığılca	2	15.00
Gölyaka	3	13.40
Kaynaşlı	4	11.53
Çilimli	5	07.75
Gümüşova	6	04.91
Cumayeri	7	04.29
Akçakoca	8	02.52

The thematic map of the analysis values is shown in Figure 4. The hazard value is increasing towards the southern parts of Düzce province. The hazard values of the earthquake towards the red tone from the blue tones are increasing.

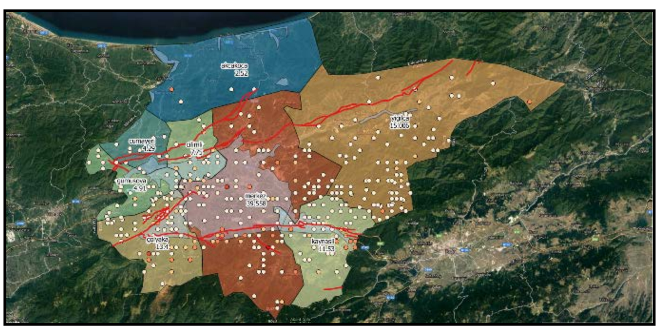

Fig.4. Demonstration of AHP Earthquake Hazard Values of Düzce Districts with Thematic Map by QGIS

D. EARTHQUAKE HAZARD ANALYSIS WITH FUZZY LOGIC

Fuzzy logic is a concept that first appeared in 1965 when Dr. Lotfi A. Zadeh published an article on "Information and Control" in this issue. Fuzzy logic is a very valuable form of logic that deals with values that are roughly characterized and can be reasonably judged from absolute and exact values [11]. Fuzzy logic holds intermediate values such as very long, long, medium, short, and very short instead of long-short, as in human logic, and everything is represented by values in the range [0,1]. In summary, fuzzy logic is preferred if the results in a system need not be precisely defined, if the results are to be displayed in range values, or if mathematical criteria are to be determined and classified as adjectives [11 - 18]. The reason of comparison fuzzy logic with AHP is time and location of the disaster is uncertain. Using fuzzy logic method, a model with current data is created. In this model, earthquake hazard is defined as low, medium and high. After the earthquake disaster, the fuzzy logic model will be used to model the current earthquake hazard values only by entering the current system.

In the Fuzzy Logic Method, criterion values are used in a similar manner to the AHP method. For this, Fuzzy Logic Designer plugin is used via MATLAB. Membership functions were created separately for each criterion to reach the results obtained in the AHP with the existing values. Afterwards, the basic rule table is defined, for example, if the number of epicenter points, the fault length and the alluvium area of a district are low, earthquake hazard is low and in the opposite case, the danger value is high. Furthermore, the decision maker has been defined according to various probability interpretations of the rule table. All rules were evaluated and earthquake hazard analysis was made according to the values that each district had. Figure 5 shows the general structure of the fuzzy logic model. From the left to the right in the direction of flow, firstly the rules are added to the rule table which is created together with the values that the districts have for each criterion.

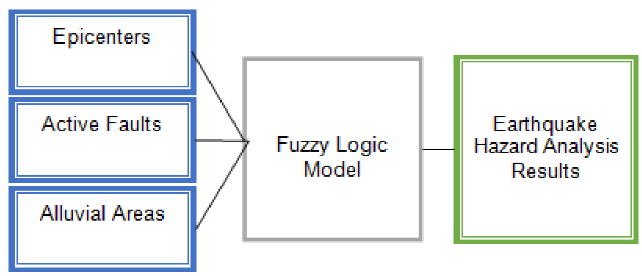

Fig.5. General structure of Fuzzy Logic.

The values used in the generated fuzzy logic model are as in Table III.

Table III. Input and Output Values Used in Fuzzy Logic Model

	Range	Low	Medium	High
Epicenters (Figure 6)	[0 200]	[0 0 8 55]	[16.5 55.8 117]	[55 168 200 200]
Active Faults (Figure 7)	[0 120]	[0 0 7.2 40]	[0 0 7.2 40]	[0 0 7.2 40]
Alluvial Areas (Figure 8)	[0 400]	[0 0 11 66]	[0 73.2 149.1]	[66 191.4 400 400]
Earthquake Hazard Results (Figure 9)	[0 30]	[0 0 0.0348 5.25]	[2.303 5.518 6.533 10.2]	[5.3 16.2 30.3 30.3]

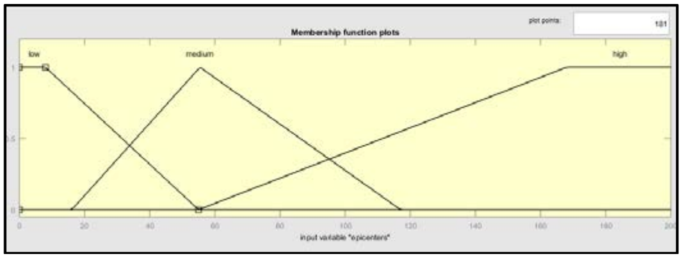

Fig.6. Membership Function of Earthquake Epicenter Points Data

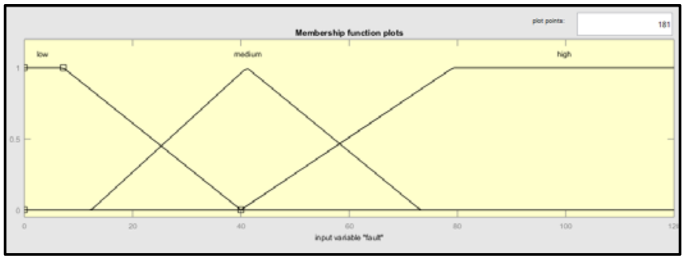

Fig.7. Membership Function of Active Faults Data

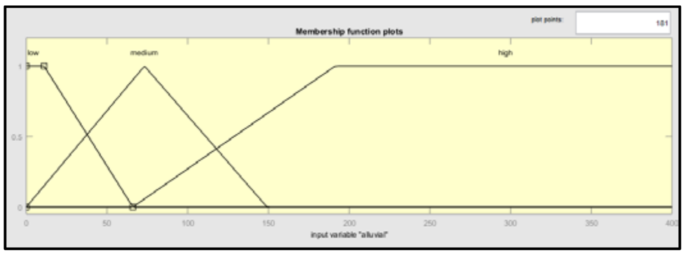

Fig.8. Membership Function of Alluvial Areas Data

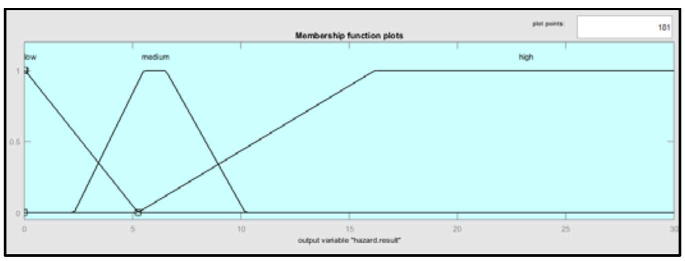

Fig.9. Membership Function of MATLAB Fuzzy Logic Designer Results

1. If (epicenters is low) and (fault is low) and (alluvial is low) then (hazard.result is low) (1)
2. If (epicenters is high) and (fault is high) and (alluvial is high) then (hazard.result is high) (1)
3. If (epicenters is medium) and (fault is medium) and (alluvial is medium) then (hazard.result is medium) (0.8)
4. If (epicenters is medium) and (fault is medium) and (alluvial is low) then (hazard.result is medium) (0.2)
5. If (epicenters is low) and (fault is medium) and (alluvial is low) then (hazard.result is low) (0.5)
6. If (epicenters is medium) and (fault is low) and (alluvial is low) then (hazard.result is low) (0.5)

Fig.10. Rule Table

After the fuzzy model is constructed, the earthquake hazard values obtained according to the input values are obtained visually with the rule viewer. In Figure 11, the hazard result values change dynamically according to the values obtained by moving the vertical red line with the mouse to the right or left by hand. The earthquake hazard value of 18.80 is obtained, which is count of epicenter of the earthquakes with a magnitude greater than 3 is 100, length of faults is 60 km and alluvial area is 200

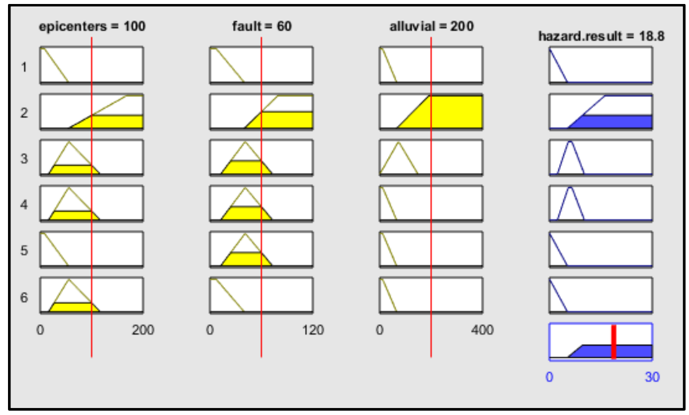

Fig.11. Visual View of Rule Table.

km^2. This value should be multiplied by 2 to normalize with AHP results. Equivalent AHP value is 37.60%. While the basic rule table was constructed, the values of each districts were evaluated separately for each criterion. Values close to those obtained with AHP were found. In this way, earthquake hazard analysis can be performed quickly with the values to be entered via MATLAB with the dynamically changing numbers.

III. FINDINGS AND DISCUSSION

The results obtained by using AHP and Fuzzy Logic methods are shown in Table 4. In Figure 12, the results obtained from AHP and Fuzzy Logic Model for each district is similar to the correlation value of 0.996.

Table.4. Earthquake Hazard Values Obtained with AHP and Fuzzy Logic Models of Düzce Districts.

District	Rank	AHP Values (%)	Fuzzy Logic Values	Fuzzy Logic Values * 2 (%)
Merkez	1	39.55	19.70	39.40
Yığılca	2	15.00	06.24	12.48
Gölyaka	3	13.40	06.20	12.40
Kaynaşlı	4	11.53	05.73	11.46
Çilimli	5	07.75	03.87	07.74
Gümüşova	6	04.91	02.00	04.00
Cumayeri	7	04.29	01.92	03.84
Akçakoca	8	02.52	01.75	03.50

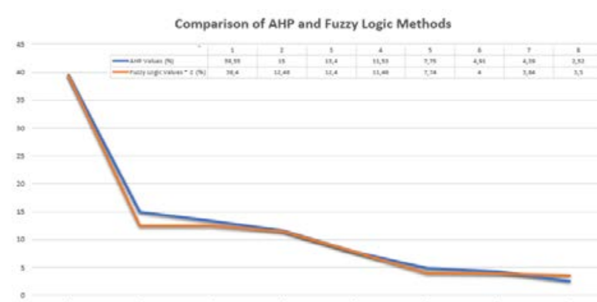

Fig.12. Demonstration of Results Obtained by Using AHP and Fuzzy Logic Methods.

IV. RESULTS AND RECOMMENDATIONS

Accelerating and analyzing earthquake hazard analysis is possible by evaluating several parameters. With AHP and Fuzzy Logic methods, earthquake hazard analysis can be done and the results are compatible with each other. According to the three criteria, earthquake hazard analysis for Düzce central district is the most risky district with 39% .Yığılca, Gölyaka and Kaynaşlı districts are medium risky districts. Çilimli, Gümüşova, Cumayeri and Akçakoca were determined as the least risky districts. The use of fuzzy logic for a dynamic earthquake hazard model is a quick solution. In the classical AHP Method, post-disaster values are re-adding and recalculations for each criteria and alternatives. In the fuzzy logic, after post-disaster only changed values of criteria or alternatives are updating via MATLAB fuzzy logic extension and then updated earthquake hazard analysis results can be obtained.

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