SEISMIC RISK ASSESSMENT USING GEOGRAPHICAL INFORMATION SYSTEM (GIS) WITH ANALYTIC HIERARCHY PROCESS (AHP): ESKİŞEHİR, TURKEY

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January 2018

FINAL APPROVAL FOR THESIS

This thesis titled "Seismic Risk Assessment Using Geographical Information System (GIS) with Analytic Hierarchy Process (AHP): Eskişehir, Turkey" has been prepared and submitted by Suharto Sandayan Esmael in partial fulfillment of the requirements in "Anadolu University Directive on Graduate Education and Examination" for the Degree of Master of Science in Geographical Information System and Remote Sensing Department has been examined and approved on 03/01/2018

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ÖZET

Coğrafi Bilgi Sistemi ile Analitik Hiyerarşi Süreci Kullanarak Deprem Risk Değerlendirmesi: Eskişehir, Türkiye

Suharto Sandayan ESMAEL

Coğrafi Bilgi Sistemileri ve Uzaktan Algılama

Anadolu Üniversitesi, Fen Bilimleri Enstitüsü, Ocak 2018

Danışman: Prof. Dr. Can AYDAY

Bu çalışma, analitik hiyerarşi işleminin kullanıldığı coğrafi bilgi sistemi kullanılarak Türkiye'de Eskişehir ilinin sismik riskini değerlendirmeyi hedeflemektedir. Çalışmanın amacı, litoloji, fay hattı ve merkez üstü kriterleri göz önüne alınarak, Eskişehir'in hangi bölgelerinin depreme eğilimli olduğuna cevap bulmaya çalışmaktır. Çalışmadaki temel tartışmalarından bir diğeri, GIS ve AHP temel alınarak üç faktör arasında aynı sonucu veren risklerin hesaplanmasıdır. Çalışmanın sonucunda ilin Afet Risk Azaltma Yönetimi Programı için farklı öneriler ortaya çıkmıştır. İlki, litolojiye göre AHP yöntemi kullanılarak Çifteler ve Alpu ilçeleri en yüksek deprem sismik riskine sahip olduğunu ve GIS yönteminde ise en yüksek sismik riski Tepebaşı ilçesi göstemektedir. İkincisi, fay hattıya gore, AHP yöntemi kullanılarak en yüksek sismik risk Tepebaşı ilçesindedir. Diğer yandan GIS yöntemine dayalı olarak İnönü, Mihalgazi, Tepebaşı, ve Sarıcakaya en yüksek sismik risk göstermiştir. Üçüncüsü, merkez üssü temel dayanarak AHP yönteminde diğer faktörler gibi en yüksek sismik risk yine Tepebaşı ilçesindedir ve GIS yönteminde ise İnönü, Sarıcakaya, ve Alpu ilçesindedir. Dördüncüsü, üç senaryo kullanılarak Tepabaşı ve İnönü ilçelerinin Eskişehir ilinde en yüksek depremselliğe sahip olduğunu göstermektedir. Son olarak, GIS ve AHP yöntemine dayalı olarak, üç senaryoden elde edilen sonuç, Tepebaşı ilçesinde benzer bir sismik risk oluşturmaktadır.

Anahtar kelimeler*:* Deprem Riski, Ağırlık Analizi, Analitik Hiyerarşik İşlem, Coğrafi Bilgi Sistemleri

ABSTRACT

Seismic Risk Assessment Using Geographical Information System (GIS) with Analytic Hierarchy Process (AHP): Eskişehir, Turkey

Suharto Sandayan ESMAEL

Geographical Information System and Remote Sensing

Anadolu University, Graduate School of Science, January 2018

Supervisor: Prof. Dr. Can AYDAY

This study aimed to assess the seismic risk using geographical information system with the used of Analytic hierarchy process in the province of Eskişehir, Turkey. Specifically, this paper sought to answer which area in the province of Eskişehir is highly prone to earthquake based on lithology, fault lines, and epicenter. Based on the three criteria, which area of the province is highly prone to earthquake. Lastly, based on GIS and AHP, which among these three factors produce the same result of computation of risks. The result of the study creates different suggestions for the Disaster Risk Reduction Management Program of the province. First, based from lithology, the result in AHP method shows that the district of Çifteler and Alpu has the highest risk of earthquake seismicity while the result of GIS method shows that the district of Tepebaşı has the highest risk of seismicity in Eskişehir province. Second, based from fault lines, the result in AHP method shows that Tepebaşı has the highest risk of seismicity while based on GIS method, the district of İnönü, Mihalgazi, Tepebaşı, and Sarıcakaya has the highest risk of seismicity. Third, based on epicenter, the result in AHP method shows that Tepebaşı has the highest risk of seismicity while based on GIS method, the result shows that İnönü, Sarıcakaya, and Alpu has the highest rate of seismicity. Fourth, using the three scenarios, the result shows that the district of Tepebaşı and İnönü has the highest rate of seismicity in the province of Eskişehir. And lastly, based on GIS and AHP method, the result from scenario three produce a similar seismic risk in the district of Tepebaşı.

Keywords*:* Seismic Risk, Weighting Analysis, Analytic Hierarchical Process, Geographic Information Systems

STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific ethical principles and rules throughout the stages of preparation, data collection, analysis, and presentation of my work; that I have cited the sources of all the data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this study has been scanned for plagiarism with "scientific plagiarism detection program" used by Anadolu University, and that "it does not have any plagiarism" whatsoever. I also declare that, if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that are involved.

Suharto Sandayan Esmael

DEDICATION

To my beloved family who never stops believing me to achieve all my dreams. And most especially, to ALLAH (s.w.a) who gives me the opportunity to achieve who am I and what I have today.

ACKNOWLEDGEMENT

I genuinely appreciate the endless effort and support from my beloved family to complete my studies. To my mother, **Saimona Sandayan Esmael**, thank you for always lifting my spirit and emotion whenever I feel down, and also being my inspiration at all time. To my Father, **Abduladzis Mohammad Esmael**, he is always my great hero, he taught me to love my own Bangsa (Identity) and my homeland with his action and sacrifices, which the reason I decided to take this master degree. To my brothers and sister, **Normina, Nasrullah, Khalid, Noraisa, Zuhair, Mohaimen, Jasmina, and Abduljabar**, thank you for the tremendous support and showing no doubts with my chosen path.

To all my friends from Philippines, Turkey, and from other part of the globe, thank you very much for trusting me. To **Barjunaid Cadir, Asraph Omar, and Rahib Kadil**, I owe a lot of things from them, not just for supporting me in my studies but also for taking good care of me when the time of sickness. To our Organization, **Moro International Students**, thank you for the experience and learning you have imparted to each of us.

Great appreciation to my adviser **Dr. Prof. Can Ayday** for sharing his time even with his hectic schedule and his uncountable assistance with his expertise during the writing this thesis. And to his officemates who shared their professional knowledge to improve this thesis.

Above all, my most enormous gratitude to the Almighty **Allah (ﷲ)** for proving this opportunity and meet people who helped me through the process of this thesis. Thank you, Ya Allah, for letting me experience and learn whatever I learned throughout my journey.

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SYMBOLS AND ABBREVIATIONS

GIS	-	Geographical Information System
AHP	-	Analytic Hierarchy Process
NAF	-	North Anatolian Fault
IEFS	-	Inönü-Eskişehir Fault System
IDW	-	Inverse Distance Weighted
MTA	-	Maden Tetkik Arama (Turkish)
KOERI	-	Kandilli Rasathanesi ve Deprem Arastırma Entitüsü (Turkish)
ETO	-	Eskişehir Ticaret Odası (Turkish)
TUİK	-	Turkiye İstatistik Kurumu (Turkish)
AFAD	-	Afet ve Acil Durum Yönetimi Başkanlığı (Turkish)
MMI	-	Modified Mercalli Intensity Scale
WMTS	-	Web Map Tile Service
DRRO	-	Disaster Risk Reduction Office

“*Earthquakes are inevitable to happen, but victims can be lessened with proper training and Information.*”

1. INTRODUCTION

There are two kinds of disaster, man-made and natural (Sawada et al., 2011). One of the natural disasters is an earthquake that can pose catastrophe. Earthquake is one of the great devastating natural calamity that has the highest unpredictability (Daniell et al., 2017). Categorically, earthquake poses a fundamental threat to human lives, properties, infrastructures and even animal species. However, according to many seismologists, "Earthquakes don't kill people, buildings do," it is because most losses from earthquakes were caused by buildings or other human construction falling throughout during the earthquake (Nelson, 2013).

In Turkey, Eskişehir Province is close to the North Anatolian Fault (NAF) that placed the province into a hazard zone for earthquake occurrence. In Eastern Mediterranean Region, the NAF is one of the best-known dextral strike-slip faults in the globe due to its remarkable seismic activity with an extremely well-developed surface expression and importance for the tectonics (Bayrak et al., 2011). The NAF and San Andreas Fault in California has distinct similarities. The similarities include: (1) The two faults are transform faults of regional tectonic importance, and a significant length, both about 1100 km long and located at plate boundaries; (2) Both faults are dominantly strike-slip, at least in their central segments, and both are right lateral in their sense of displacement; (3) Both faults are associated with major conjugate faults that are left lateral; and (4) Both faults have generated major historical earthquake (Allen, 1982).

There are several reasons why an earthquake has a different strength of seismic activity in every location. In Eskişehir Province, two major factors may have been responsible for a destructive earthquake, i.e., the active fault lines and the lithological type of the area. However, the study included the epicenter or the earthquake history of the province during the assessment. These three elements were the vital data in Geographical Information System (GIS) and Analytical Hierarchical Process (AHP) earthquake risk assessment for the residential area of Eskişehir Province. For instance, through the use of GIS, the total length of an active fault in each district will be calculated. The calculation can help determine the prescribe buffer zone from extremely high-risk area to very low-risk area. Similarly, for the lithological type, the alluvium area will be identified and estimated. Unlike lithological computation, the analysis of number earthquake epicenters that happened in previous years will be based on its magnitude value. The AHP method, however, will use the generated data from GIS as the basis of analysis to come up with an educated decision that determines which parts of Eskişehir Province are prone to hazard and of high risk.

The GIS is a powerful software that can be used to locate earthquake-prone areas in the study area - Eskişehir Province. This will help the Disaster Risk Reduction Office (DRRO) of the province in the planning of safety measures in preparation for an incident of natural calamities like earthquake, flood, landslide, and fire. The purpose of the study is to assess the risk of earthquake and mitigate its possible threats through the use of GIS and AHP method.

1.1 Problem Statement

Turkey is located in one of the most hyperactive earthquake areas in the world, the North Anatolian Fault (NAF) which is well-known fault zone of the country. Based on 1997 Earthquake Zoning Map of Turkey, 96% of the land mass is located in different degrees of earthquake hazard where Eskişehir Province got the second, third and fourth degree of hazard from east to west (AFAD, 1997). According to Gurenko (2006), large-scale of earthquakes can occur anytime in the country that covers 70% of the population and 75% of industrial facilities.

As described by Özsayin and Dırık (2007), the Inönü-Eskişehir fault system is a northwest to west-north-west trending zone of active deformation that is about 400 km long and 15–25 km wide right-lateral trans-tensional strike-slip fault belt from Uludağ (Bursa) to the west and Lake salt (Konya) to the east, and in southern part of Eskişehir Province. Because of the fault line that transverse the province, a recurrent earthquake is possible. According to Öcal (1956), as cited by Selçuk et al. (2016), the Inönü-Eskişehir fault system pose a potentially devastating earthquake like what happened way back during 1956 when Eskişehir Province was struck by a magnitude 6.4 earthquake that devastated thousands of building.

Natural disaster like an earthquake is unpredictable and inevitable; because of such reality, it is but important for the Eskişehir Province to have preparedness and mitigation mechanism for the eventual coming of such disaster. One way to craft preparedness and mitigation measures is to determine the hazard zone of the province. The hazard zone especially the high-risk areas can be determined by conducting studies using the GIS and AHP method. The appropriate identification of hazard zone will evade possible casualties in time of earthquake calamity. The Eskişehir Province nowadays experienced growing industrial developments as well as population growth that necessitate earthquake awareness campaign for its residents that is in consideration to the fact that the province is situated near or at least some of its districts are in the fault line. The awareness campaign can be done through earthquake drill and information drive.

This study sought to answer the following questions:

1) Which area is highly prone to earthquake risk regarding on lithology criterion?
2) Which area is highly prone to earthquake risk regarding fault lines criterion?
3) Which area is highly prone to earthquake risk regarding epicenters criterion?
4) Using the three scenarios, which area is highly prone to earthquake risk based on lithology, fault lines and epicenters criteria?
5) Based on GIS and AHP method, which among the three criteria produced approximately the same results?

1.2. Purpose of the Study

The main purpose of the study is to identify the specific areas in Eskişehir Province which have the highest risk of an earthquake. Specifically, the study is aimed to determine the areas that are in more prone to earthquake based on the three geological criteria, i.e., lithology, fault line, and earthquake epicenters with the use of GIS and AHP method.

The result of the study will give several benefits to the different sectors in Eskişehir Province. First, the province can utilize the study findings in their earthquake preparedness and mitigation planning as the study findings can pinpoint the areas or districts that are in the high possibility of seismic hazard that may cause a fire, building collapse, and flood caused by dam breakdown. Second, the study findings can be useful in urban planning and infrastructure coding in real estate and commercial infrastructures. Third, the study result can guide the DRRO in its earthquake information awareness campaigns as well as its personnel assignment distribution for a faster and efficient response during actual earthquake occurrence. Lastly, the study results can be utilized by Provincial Health Ministry in its health personnel assignment distribution as well as in the construction of a sufficient number of health facilities to strategic locations within the province.

1.3. Scope and Delimitation

The study is aimed to assess the seismic risk in Eskişehir Province. The analysis includes 14 districts namely: 1) Odunpazarı, 2) Tepebaşı, 3) Alpu, 4) Beylikova, 5) Çifteler, 6) Günyüzü, 7) Han, 8) İnönü, 9) Mahmudiye, 10) Mihalgazi, 11) Mihalıççık, 12) Sarıcakaya, 13) Seyitgazi, and 14) Sivrihisar. There are three criteria that will be considered during the analysis, i.e., lithology, fault line, and epicenter. The three criteria hold particular scope of the area as its danger zone. In lithology criterion, the alluvium area is considered as the danger zone, while in fault line criterion, the nearest area around it is considered as the risk perimeter. The epicenter criterion, however, considers the earthquake magnitude value as an indicator in determining of earthquake risk capacity and scope.

During the assessments and analysis, three software were employed that include, ArcGIS and QGIS for GIS method, and Microsoft Excel for the AHP decision making. The data were retrieved from the official website of Maden Tetkik Arama Genel Müdürlüğü (MTA) and Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü (KOERI). Lithology and fault line data were retrieved from the server of MTA through the connection of GIS software to the MTA server. While the epicenter data were downloaded from the website of KOERI through the manual input of data description.

1.4. The Study Area

The study area is Eskişehir Province, Turkey which is located in the northwestern region of the country. The neighboring provinces of Eskişehir are Bilecik to the northwest, Afyon to the southwest, Kütahya to the west, Konya to the south, Bolu to the north and Ankara to the east**.** Its total land area is 14,108.2 km^2 which is 1.8 % of Turkey total land area. The straight distance between Eskişehir and Istanbul is 191 km, and 200 km from Eskişehir to Ankara (Figure 1).

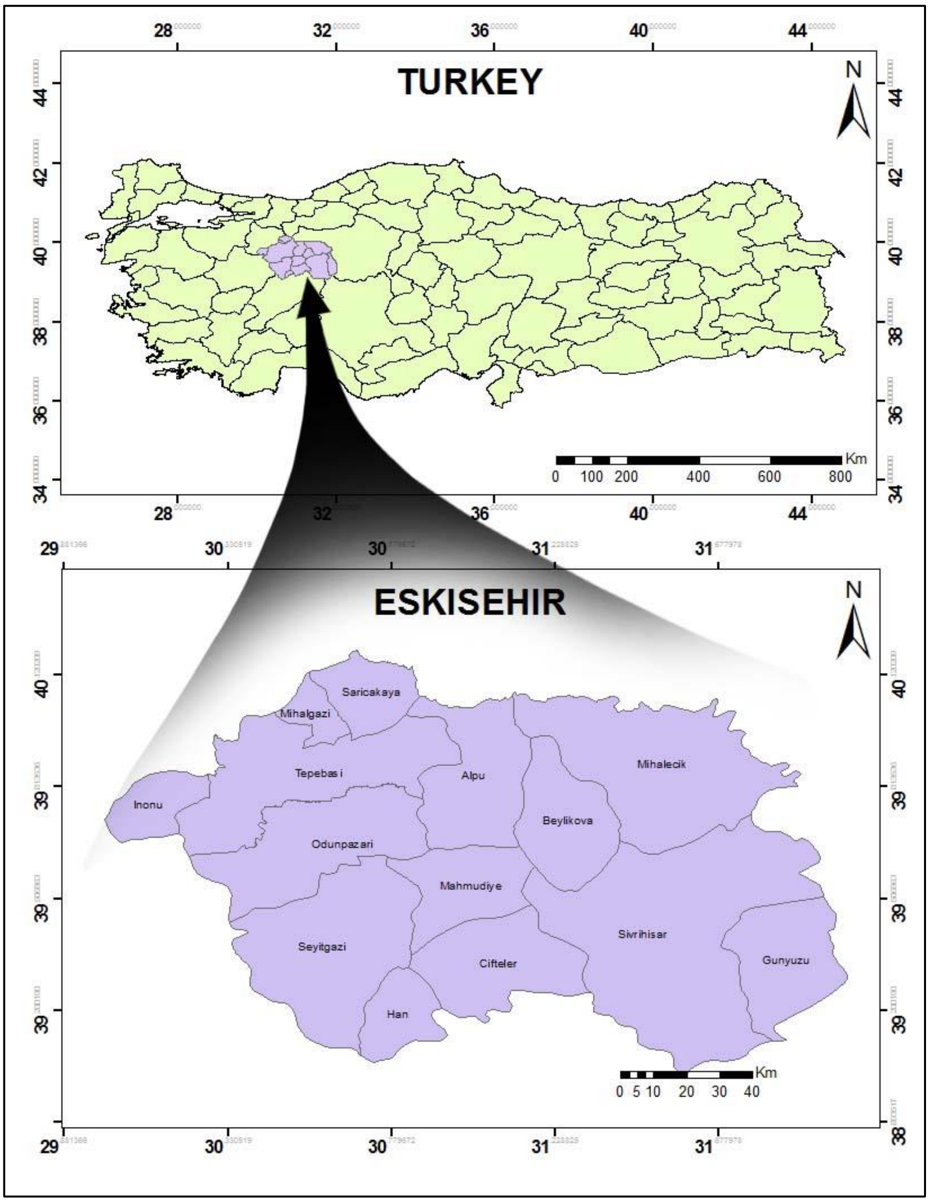


Figure 1.1. *Eskişehir Province, Turkey*

Based on industrial, economic and social development, Eskişehir Province is one of the fast-growing provinces of Turkey. The province is known to have the geographical advantage due to its position in the west portal of Anatolia. The major industrial business of the province includes mining, railway, and aircraft. The favorable geographical location and good industrial businesses made the province considered as one of the economic centers of Turkey. According to the chamber of commerce of the province, the Eskişehir Ticaret Odası (ETO), Eskişehir ranked 7th in social-economic growth among the 81 provinces of the country (ETO, 2014).

Eskişehir Province has 14 districts namely: 1) Odunpazarı, 2) Tepebaşı, 3) Alpu, 4) Beylikova, 5) Çifteler, 6) Günyüzü, 7) Han, 8) İnönü, 9) Mahmudiye, 10) Mihalgazi, 11) Mihalıççık, 12) Sarıcakaya, 13) Seyitgazi, and 14) Sivrihisar. And according to Turkiye İstatistik Kurumu (TUİK, 2016) - the Turkish Statistical Institute, the total population of the province reached 844.842 based on 2016 statistics record. Majority of the populations, however, are situated in districts of Tepebaşı and Odunpazarı, the districts formerly known as Merkez.

There are two universities in Eskişehir Province, the Osmangazi University and Anadolu University. The influx of students in both universities makes the province to be more populated and reputed to be a “Student Capital” in Turkey.

Eskişehir Province is near to the North Anatolian Fault (NAF) of Turkey. The NAF is one of the most active right-lateral strike-slip faults in the world. The NAF also made Turkey under frequent occurrence of major destructive earthquake at least 2000 BC. The country has a long history of devastating earthquakes that killed a large number of people and cause economic loss. The most recent incidence of the earthquake was the magnitude 7.8 earthquakes in Izmit and magnitude 7.2 earthquake in Duzce that took place sometime in August and November of 1990 (Bayrak et al., 2011).

And according to Afet ve Acil Durum Yönetimi Başkanliği Deprem Dairesi Başkanliğı (AFAD, 1996), Eskişehir Province ranked second, third, and fourth zone in terms of risk to earthquake hazard. Based on the map in Figure 2, the country is divided into five zones with potential danger ranging from 1 (highest risk) to 5 (lowest risk). The map shows the west part of Eskişehir Province is in the second degree of earthquake danger or hazard. The western part of Eskişehir is considered as the most populated area of the province that can aggravate the risk once earthquake will strike the province again (AFAD, 1996).

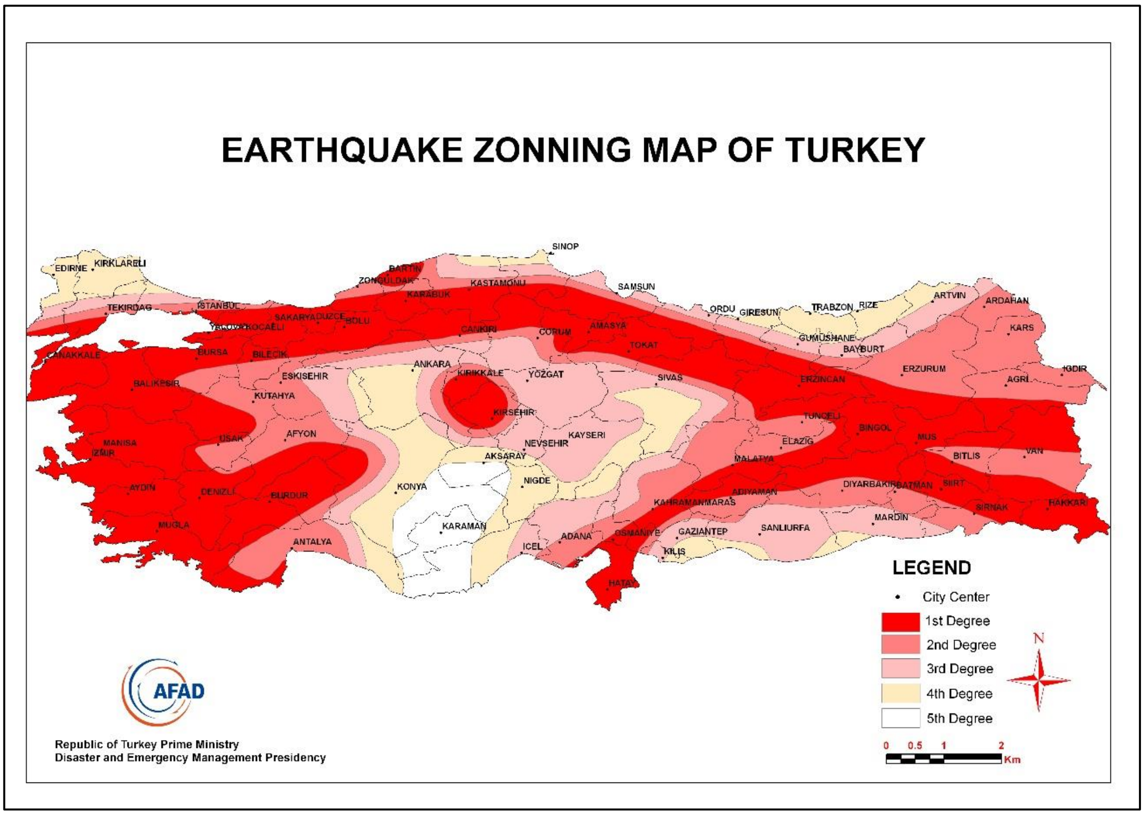


Figure 1.2. *Earthquake Zoning Map of Turkey. Retrieved from the official website of Disaster and Emergency Management of Turkey (1996)*

2. PREVIOUS WORKS

The study is anchored on two previous studies. The first model study is the research of Öztel et al. (2002) on Disaster Information System with Proactive Systems (Önerici Sistemler ile Afet Bilgi Sistemi). The said study assessed the districts of Kütahya in terms of proneness to earthquake risk using the GIS and AHP method. The study developed a software using the concept of AHP to determine the risk in the area using the fault line, lithology, and epicenters as criteria. The GIS was employed to get the value of each criterion used in AHP method. While the fault line, lithology, and epicenter values were generated using the power of GIS. Furthermore, in the model study, the researchers performed the following activities in Kütahya: 1) calculated the length of a fault line in every district of Kütahya in a kilometer, 2) measured the total alluvial lithology area, and 3) counted the earthquake epicenter in every district.

The second model study is the study of Pekkan and his colleagues that was conducted in 2015. The study investigated the seismic risk in the residential area of Tepebaşı District, in Eskişehir Province. In this model study, the researchers used site amplification, soil liquefaction, and simple weighting method to come up a hazard map of Tepebaşı District. The map of site amplification and soil liquefaction for the weighting method were used that generated the final result of their study. In addition, the method under suitability analysis helps analyze site conditions that are based on multiple criteria. In deriving the total value placed in a new layer as the suitable result, each criterion assigned a weight ratio for suitability analysis, and criteria value classified to a common suitability scale by multiplying each criterion weighted value by its weight ratio (Pekkan et al., 2015).

Site amplification happens when near-surface deposits increase shaking felt at the surface compared to the expected bedrock shaking (Kramer, 1996). Categorically, site amplification refers between the ground surface and bedrock and depends on several factors; the composition of soil layers, S-wave velocities, soil densities, internal damping of the individual layers (Kokusho and Sato, 2008). Liquefaction, on the other hand is a phenomenon where a mass of soil loses a high percentage of its shear resistance. Nevertheless, when subjected to cyclic, monotonic, or shock loading, and flows in a manner approaching a liquid until the shear stresses acting on the mass was as low as the reduced shear resistance (Rauch, 1997).

Seismic risk assessment is necessary for this study considering its importance in hazard mapping, preparedness, and mitigation for earthquake occurrence. While all seismic criteria have the potential destruction during an earthquake, based on the record of most recent world earthquakes, the damage from site effects has an excessively high impact on buildings. One earthquake that can prove the possible damage in site amplification is the magnitude 6.3 earthquake in Christchurch, New Zealand that took place on February 22, 2011 (Bradley and Cubrinovski, 2011).

There are many ways to assess seismic risk, for example, a researcher can use the different or new method, or will use a different type of criteria in the same approach. For instance, the study of Seismic vulnerability and risk assessment of Kolkata City, India that used four type of criteria 1) Land use/Land cover, 2) Population density, 3) Building Typology and 4) Age and height. The study micro-zoned seismic hazard of the city by integrating seismological, geological and geotechnical themes in GIS. (Nath et al., 2015). Furthermore, in the study of Erden and Kaman (2012) conducted in Küçükçekmece Region, Istanbul, Turkey, five different criteria of seismic risk analysis were used that include, 1) Field topography or the slope, 2) Source to distance or the epicenter, 3) Soil classification or lithology, 4) Liquefaction potential, and 5) Fault/focal mechanism. This study integrated AHP and GIS to generate earthquake mitigation parameters and hazard maps.

Extensive studies that have been conducted about the effects of topography that amplify the seismic ground motion and affecting parameters on the behavior of topography; however, those studies were based on wave propagation theory. Those studies have shown that the main factor in the creation of vertical motion component and amplifying ground motion surface was the reflected waves from slope surface. The waves generated by the earthquake in the presence of slope topography include P-waves, SV-waves, Rayleigh, and SP waves. The effect of the earthquake attenuates as the distance from the epicenter of the earthquake increases. And the source to site effect was one factor in the study for the reason that the closer the epicenter the higher possibility of effects (Bouckovalas and Papadimitrous, (2005) and Assimaki et al., (2005). And although there was still no agreement on the modeling of effects of the topography or slope in seismic risk analysis, this criterion was considered as an essential factor in earthquake hazard. According to Eurocode 8 standard, field topography has an amplification effect on height and slope angle (European Committee for Standardization, 2004).

In reiteration, there are several factors that can influence seismic analysis. First among the factors is soil classification which posits that the shear wave velocity is an important parameter for evaluating the dynamic behavior of soil in the shallow subsurface. Consequently, the site characterization in calculating seismic threats is usually based on the near-surface shear wave velocity (Kanlı et al., 2005). And the average shear-wave velocity is between 0 and 30-meters depth (OpenSha, 2010). The second factor, however, is the liquefaction potential of the area which is also commonly associated with the massive earthquake. Lastly, the fault/focal mechanism which was considered as the common source of the earthquake in the entire globe (Kanlı et al., 2005).

And in the Probabilistic Seismic Hazard Analysis for Quetta City, in Pakistan, Rehman et al. (2012) concluded that the soil and possible fault effects should be used in the seismic risk analysis. However, Farangitakis et al., (2016) Erden and Kaman, (2012), both used the weighted method in seismic risk analysis but employed a different way of defining of weight value to its criteria. In the Farangitakis and his colleague's study, the weight of criteria was based on the Nurses' Global Assessment of Suicide Risk (NGASR). On the other hand, Erden and Kaman used the AHP in determining the ranking of its criteria, and its relative weight value. According to Mann (1995), the AHP is a decision support instrument that can be employed in solving complex decision problems. It has procedures of a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The pertinent data can be derived by using a set of pairwise comparisons.

3. METHODOLOGY

Two different methods namely the Geographical Information System (GIS) and the Analytic Hierarchy Process (AHP) were used in the study. GIS was used to identify the risk area using the spatial data of lithology, fault line, and epicenter in the study area. Assigning of different weights for each spatial data and overlay all together came up a single map that shows the specific area with a different degree of risk. AHP also used the three geological elements, i.e., lithology, fault line, and epicenter as its criteria to identify the earthquake-prone area in the study locale but employed a different method. The area number of alluvium lithology, length of the fault line, and the number of epicenter within every district of the study area were calculated in GIS and used in AHP for decision making. And each value of the three geological elements in every district was compared to each other that resulted in the identification of district with high risk from earthquake base on the composite existence of the three geological elements.

The study formulated three scenarios to see which weight value was more applicable at the end of the process because the weight importance of three geological elements or the criteria was not known. The three formulated scenarios have different assignment of weight importance to each geological elements that were used in both methods. The result of each scenario from the two methods was compared to see the similarity of each scenario from the two methods. The scenario with more similarities served as the appropriate weight importance value to the criteria and at the same time served as the final result of the study.

3.1. Geographical Information System (GIS)

GIS software is designed to store, manage, retrieve, visualizes, and analyze all types of geographical feature and their characteristics. It helps researchers to quickly understand the raw data of the earth surface by transforming it into graphical data. GIS is now widely used by different entities in urban development and risk assessment. (Armenakis et al., 2017).

There are four basic ideas of GIS method that were employed in the study, 1) Identify, 2) Create, 3) Analyze, and 4.) Display. First, the type of data needed for the analysis was identified which include lithology, fault line, and epicenter. Second, a spatial data from the identified geological feature was created. Third, the spatial data was analyzed using different tools of the GIS software. And fourth, displayed the resulting map from the analyzed data.

There are also different analysis in GIS to be done to identify the earthquake risk area such as the Inverse Distance Weighted (IDW) Interpolation, Multiple Ring Buffer, and the Weighted Overlay Analysis.

3.1.1. Inverse Distance Weighted (IDW) Interpolation of epicenter

The IDW Interpolation was a tool used to identify the risk effect of each earthquake epicenters using its magnitude value. The epicenter is the point of an earthquake on the earth's surface that creates a vibration around it and travel depends on its magnitude, vertically below is the hypocenter or focus. Epicenter can be located using three seismographs that recorded the same earthquake scenario. (Figure 3). The distance from the earthquake epicenter to seismograph location serves as the radius of the circle. The area where the three circle meets is the location of the earthquake epicenter (UPSeis, 2007).

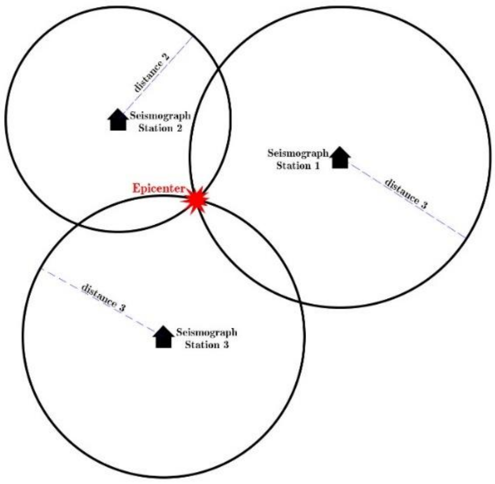


Figure 3.1. *Locating of earthquake epicenter using three seismographs*

The epicenter located inside and outside the Eskişehir Province was one of the criteria used to identify the hazard and risk in the study area. This type of data was considered as one of the criteria because the repetition of the earthquake in the same place is possible. According to the study conducted by Sieh (1996), the repetition of Large-

Earthquake Ruptures, confirms that some faults have shown a "characteristic" behavior during repeated large earthquakes, i.e., the magnitude, distribution, and style of slip on the fault has repetitive during two or more successive events.

The earthquake data was acquired from the official website of Kandilli Rasathanesi ve Deprem Arastırma Entitüsü (Koeri) using the latitude value of 38.87 and 40.35, and longitude value of 29.85 and 32.15 within the time period of January 01, 1900 to 2017. The data included in the study commenced from the year 1900 because according to Kandilli Rasathanesi ve Deprem Arastırma Entitüsü, this was the earliest earthquake data recorded available in Eskişehir. One example of earthquake happened sometimes on September 20, 1900, is the Denizli earthquake which recorded a magnitude of 5.0. However, it is noteworthy to point out that only the magnitude of 3.0 is needed for the study because the earthquake magnitude below 4.0 is neither hazardous to human life nor considered by most people as an earthquake. This magnitude 3.0 limit is based on the based on Modified Mercalli Intensity Scale (MMI) and Richter Scale standard. These two scales are the most popular scale used in the determination of the strength of an earthquake happening around the globe A. Phillips, 2017) (Table 1).

The earthquake data from KOERI was in a delimited text file also known as earthquake catalog. When importing this data in GIS, it automatically appeared as a point shapefile wherein each point represents the exact location of the earthquake epicenters (Figure 4). The longitude and the latitude value of each data must be precise because the final output is dependent on the defined longitude and latitude data value.

The earthquake catalog data of the study was analyzed using IDW Interpolation method. It is a powerful tool of GIS to get the average values of earthquake magnitude in the neighborhood of each processing cell. According to the first law of geography, "Everything is related to everything else (Tobler (1970), but near things are more related than distant things" (Miller, 2004). This conjoint law is the foundation of the fundamental concepts of spatial dependence and spatial autocorrelation and was utilized correctly for the IDW Interpolation method.

IDW Interpolation is a reliable technique to identify the effect of an individual earthquake in its surrounding. The IDW is also considered as an interpolation method that uses a weighted average of the attribute values, i.e., earthquake magnitude from nearby sample points to estimate the scale of that attribute at non-sampled locations.

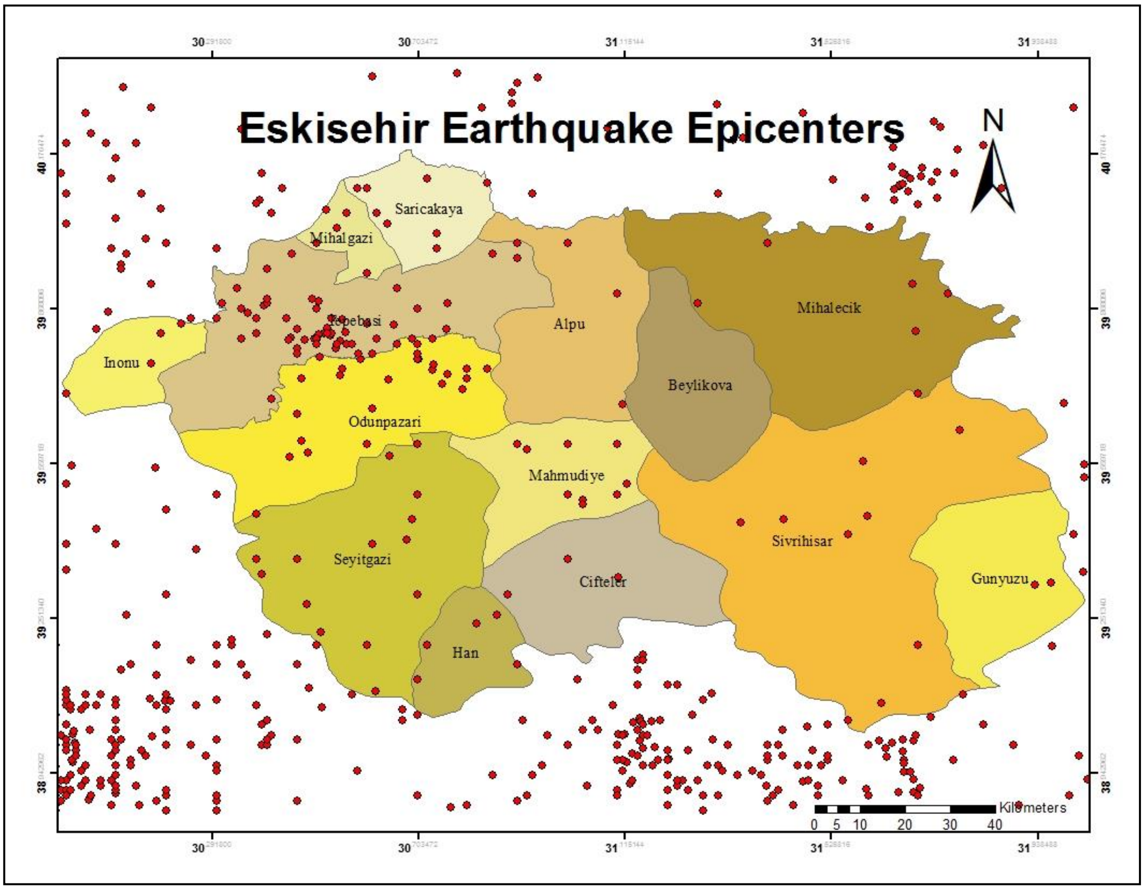


Figure 3.2. *Earthquake epicenters within Eskişehir province and its neighbor provinces (http - 1)*

Table 3.1. *Richter Scale and Mercalli Intensity Scale (http - 2)*

Richter Scale (Magnitude)	**Mercalli Intensity**	**Description/Damage**
2	I	**Instrumental.** Not felt except by a very few under especially favorable conditions.
	II	**Feeble.** Felt only by a few persons at rest, especially on upper floors of buildings.
3	III	**Slight**. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
	IV	**Moderate.** Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
4	V	**Rather Strong.** Felt by nearly everyone; many awakened. Some dishes, windows were broken. Unstable objects overturned. Pendulum clocks may stop.
5	VI	**Strong.** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	VII	**Very Strong.** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys were broken.
6	VIII	**Destructive.** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
7	IX	**Ruinous.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
	X	**Disastrous.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
8	XI	**Very Disastrous.** Few, if any, (masonry) structure remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of servise. Earth slumps and land slips in soft ground. Rails bent gently.
	XII	**Catastrophic.** Damage Total, Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

3.1.2. Rasterization and reclassification of lithology

Geological map of Turkey was available in raster file from the official website of Maden Tetkik ve Arama Genel Müdürlüğü (MTA), the General Directorate of Mineral Research and Exploration - the institution that aims in conducting scientific and technological research on mineral exploration and geology (Figure 6). The geological map from the MTA website acquired as Web Map Tile Service (WMTS) specification. WMTS is an international specification for serving digital map over the web using cached image tile through the connection of any GIS software to the server of MTA drive to access the available data and serves as an imported data during the process (ArcGIS Server, 2016).

To use the WMTS for analyzing the hazard and risk of an earthquake in a study area, it requires conversion of raster data into a spatial data by means of digitization. In GIS, digitization is a process of tracing the exact shape of the geographical feature (land, buildings, trees, river, roads, etc.) using point, line, and polygon wherein the result of the process is called spatial data. Spatial data are also known as geospatial data is about information that identifies the geographic location of features and boundaries on earth surface. (Surve and Kathane, 2014).

The lithology of the Eskişehir Province was digitized to convert the WMTS data into a vector data. There were thirty-four lithological types in the area which include alluvium, and the rest was rock types. Alluvium was categorized in the study as risky lithology from seismicity because of its fundamental characteristics when an earthquake occurs. The map was categorized only into two categories, i.e., a soft ground which is the alluvial type and firm ground which represent the rock type. Categorically, all of the rock types were merged into single polygon file since the earthquake S-wave cannot penetrate freely because of its firm characteristics while alluvium was selected as a ground type with high risk from seismicity because of its soil characteristic (Semblat, 2009).

Moreover, the lithological map was in vector file, and it was converted into raster file using the conversion tool to reclassify it. During the reclassification, there were values assigned for each class which served as the scale value during the weighted overlay analysis. The value used was ranging from 1 to 5, each value was defined from the

Seismic Risk Scale (Table 2). Since Lithological map of Eskişehir was classified only into two, one value was assigned to alluvium and five to the rock type.

The result of the digitization and classification showed that the alluvium area was all over the Eskişehir Province from the east going to the west. The alluvium in the study area was carried by the two rivers in the Eskişehir Province, the Porsuk and Sarisu River. And in terms of the district, the districts of Tepebaşı, Odunpazarı, and Alpu are found to have the largest alluvium (Figure 6).

The ground shaking is the primary reason for earthquake damage to any structures. When the ground shakes firmly, infrastructures may collapse and cause injury or even death to its occupants (IRIS and University of Portland, 2010). The geographical surface is one of the significant factors why an earthquake ground motion amplifies. Soft soils or alluvium usually amplify ground shaking. According to the study of Duke (1958), as cited by Parton and Smith (n.d.), more often structures were least damaged when established on firm ground while soft ground has always associated with the highest damage. According to Edwards (2017), site effect is the influence of the underlying soil on the local amplification of earthquake shaking.

The significant contributor to the site amplification is the speed at which the rock or soil transmits shear waves (S-waves). Shaking is higher where the shear wave velocity is lower, as the soil stiffness is directly related to the speed of shear. The Mexican earthquake in September 1985 (Smolka and Berz, 1988) and the L'Aquila earthquake in 2009 (Milana et al., 2011) caused a significant amount of casualty and severe infrastructure damage because both places have a geological surface with a low velocity.

In Figure 4, earthquake epicenters outside the area of Eskişehir Province were still considered for analysis as it can still affect the area from a distance depends on its magnitude value and the land type of the area.This theorem is proven in the history of the earthquake in Bangkok, Thailand which experienced several earthquakes coming from a distance epicenter because of its land characteristics. Based on the study of Ashford et al., (1997), it was reported that Bangkok, Thailand, although the region lies a considerable distance from any recognized active fault, it is still at risk of strong ground shaking from distance earthquakes due to soils' ability to amplify certain ground motions.

Therefore, considering a distant earthquake from a soft ground area is highly significant in assessing the risk of an earthquake.

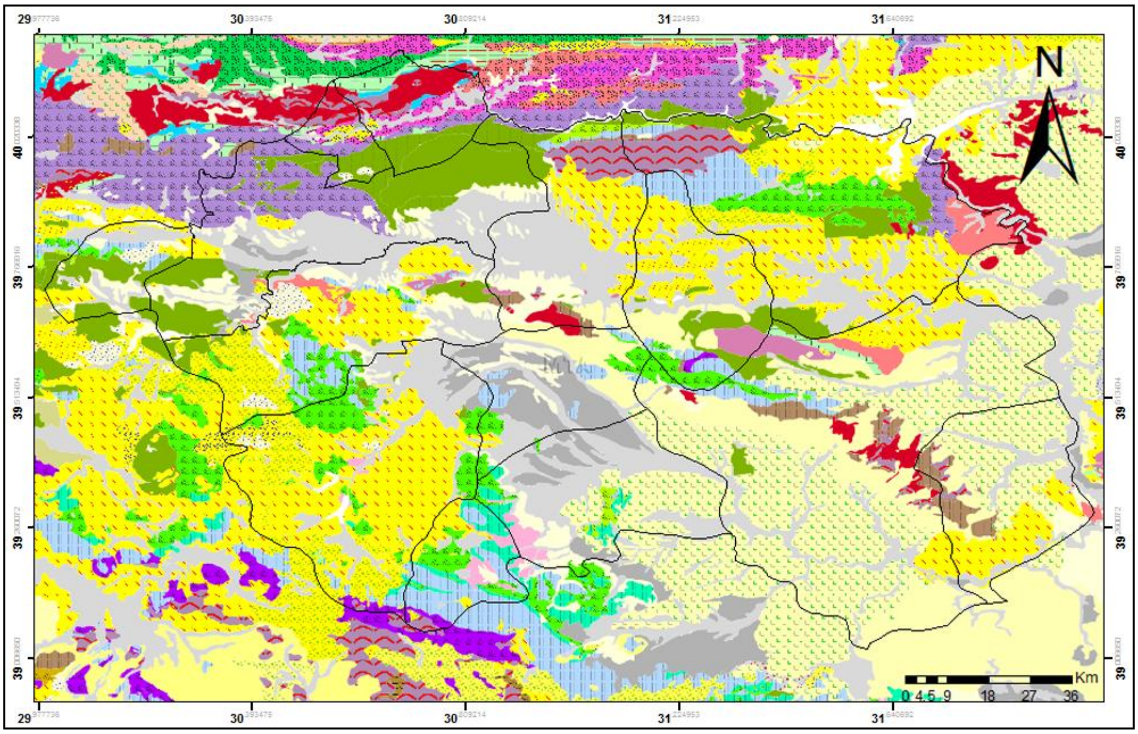


Figure 3.3. *Geological map of Eskişehir from MTA server (http - 3)*

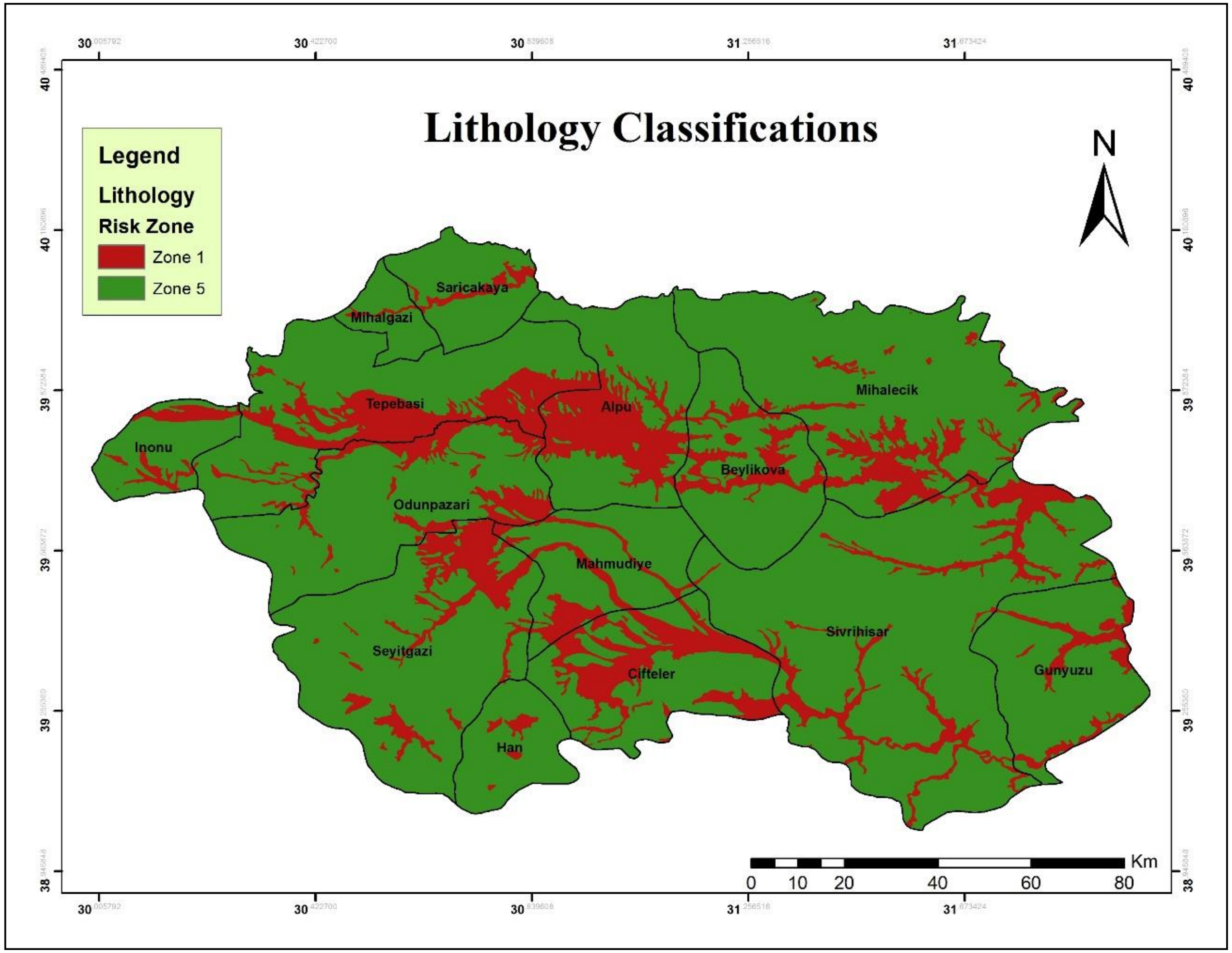


Figure 3.4. *Reclassified result of soft and firm ground lithology*

3.1.3. Multiple ring buffer on fault lines

Earthquakes are either caused by human or natural one. The man-made earthquake has many ways to include: fluid injection and fluid extraction from the earth, mining and quarrying, construction of dams and reservoirs, and nuclear testing (Jeffrey, 2005). An example of earthquake generated by a human activity was the Indian Ocean earthquake and tsunami in 2004. Many researchers' claims that a nuclear experiment that caused the catastrophe and results in a massive destruction and casualties in many countries in Asia particularly in the Province of Ache, Indonesia. Another situation of a man-made earthquake was in the Province of Sichuan, China, when the construction of Zipingpu Dam created a 7.9 earthquake magnitude and killed 80,000 of its residents (Klose, 2008).

Some of the scientists believe that other natural calamities can trigger an earthquake such as heavy rain, typhoons, volcanoes, deforestation, and climate change called "disaster triggering disaster" but these theories are still not yet confirmed because of limited evidence (Lovett, 2011). However, if this idea that natural calamity can trigger an earthquake, this notion suggests that the physical movement of the tectonic plates are the primary cause of an earthquake around the globe. The earthquake catastrophes are only increasing the stress to an object that hampers the movement of the tectonic plate and when the stress released earthquake happens (UPSeis, 2007).

Tectonic Plates are broken pieces of earth's crust and uppermost mantle. It is also known as lithospheric plates. These plates are composed of major and minor plates. Tectonic plates slowly move around that can run centimeters per year (Smart, 2016) and that movement causes a slip and collision of so-called Plate Boundaries. The surface where the action happens is called the Fault or Fault Plane where most of the earthquakes occur in it. Plate boundaries are rough enough to stock to each other and hold particular stress when stress is suddenly released explosion happens beneath the ground and it is called focus or hypocenter (Reed, 1992).

Eskişehir Province center is approximately 96 km away from one the longest and most active fault in Turkey, the NAF. It is an active right-lateral strike slip fault that moves along the transform boundary between the Anatolian Plate and the Eurasian Plate (Lamont, 2017). There is a total of 1046.46 km in length of fault existed in the Eskişehir

Province situated in its different districts. Some of the faults are considered as an active fault by the MTA. The fault line data in the study like the geological map were also retrieved from the official website of MTA. The fault line all over the country of Turkey was available as Web Map Tile Service (WMTS) specification (Figure 7). To use the data for the analysis, like the process in the previous analysis, the WMTS was converted into a spatial data by digitizing or tracing all fault line inside the area using polyline shape.

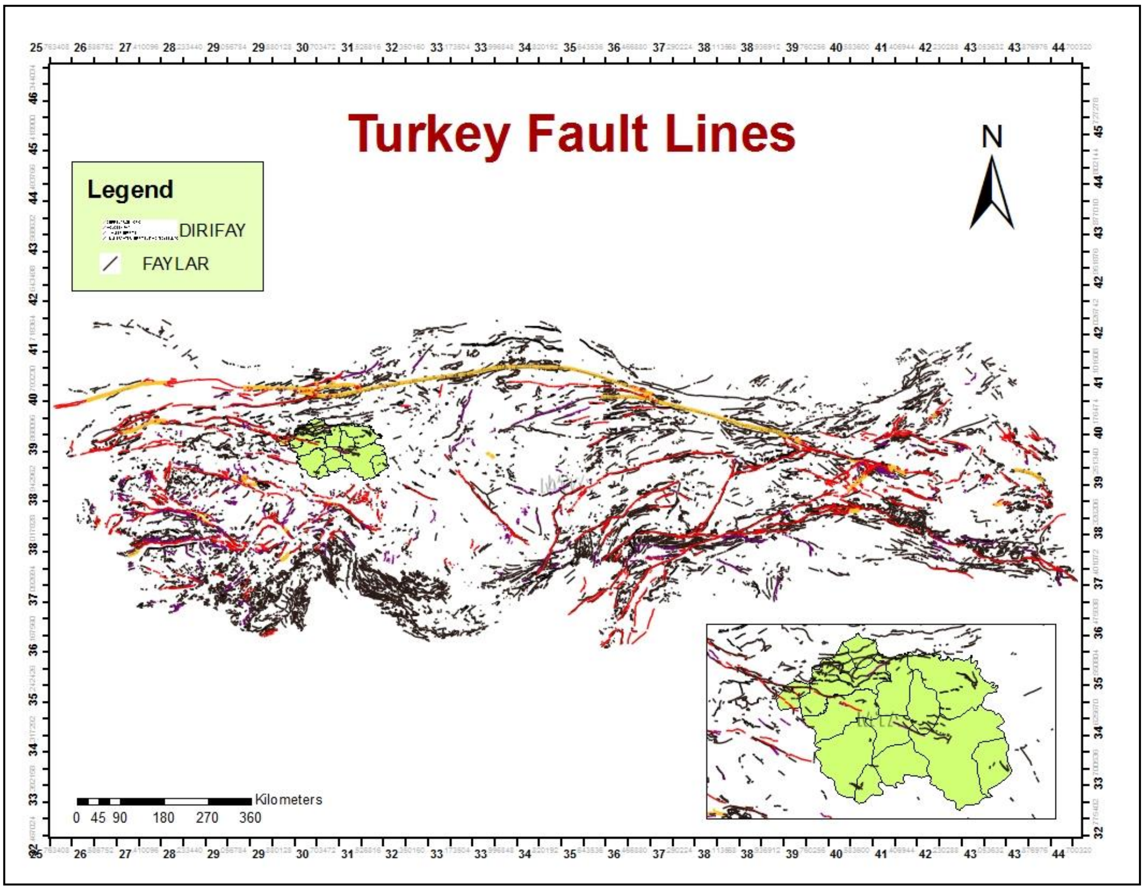


Figure 3.5. *The existing fault line within Turkey (http - 4)*

Most of the earthquake occurs around the globe was from fault lines. The further distance from the fault, the lesser effect from earthquake seismicity (Shoji et al., 2004). The study defined five parameters around the fault line that indicates the degree of risk from highest to lowest using the Multiple Ring Buffer tool. Each zone describes risk degree according to the distance from the fault line. The Seismic Risk Scale was also used in the final map results of the study to define the risk level of each zone (See Table 2).

The idea was used by Öztel et al. (2012) in their project in the Kutahya Province and modified in this study by adding more buffer zone with different distance value.

Table 3.2. *Seismic risk scale*

Distance	**Risk Zone**	**Effect**
1-5km	Zone 1	Extremely High Risk
6-10km	Zone 2	High Risk
11-15km	Zone 3	Moderate Risk
16-20km	Zone 4	Low Risk
21-Max	Zone 5	Very Low Risk

3.1.4. Weighting analysis according to three scenario

This process allows the analyzation of several rasters using a common measurement scale and weights each according to its importance. It is a suitability analysis that helps analyze site conditions based on multiple criteria. Each criterion was assigned a weight ratio for suitability analysis, and criteria value was classified to a common suitability scale by multiplying each criterion weighted value by its weight ratio, the total value was placed in a new layer as the suitable result (Esri, 2016).

The study used the tool to assess the highest risk in the province of Eskişehir. There were three primary criteria for the assessment, the effect of the earthquake epicenter according to its magnitude value, the risky Lithology of the area which was the Alluvium and the Fault Lines.

There were three results acquired from the weighted overlay and each result was based on the different scenario. The first scenario was the three criteria had an equal weight value. Second, Fault Line was higher than Epicenter and Epicenter was higher than Lithology. Third, Fault Line was higher than Lithology and Lithology was higher than epicenter. (Table 3).

Table 3.3. *Three scenarios with different priority scale*

Scenario	Criteria	Value
Scenario One	Fault Line	1
	Epicenter	1
	Lithology	1
Scenario Two	Fault Line	3
	Epicenter	2
	Lithology	1
Scenario Three	Fault Line	3
	Lithology	2
	Epicenter	1

3.2. Analytic Hierarchy Process (AHP)

The AHP introduced by Thomas Saaty (1980), is a method of decisional "Measurement through pairwise comparisons of elements and relies on the judgments of experts or a real data to derive priority scales." The AHP is now adopted around the world in a wide range of decision making, in fields such as business, healthcare, education, government, industry and disaster management. Decision maker uses AHP as a tool to translate the evaluations both Qualitative and Quantitative into a multi-criteria ranking.

The use of AHP in the study was to help decide which GIS result from the three scenarios was more appropriate or more reasonable by matching its results. In AHP method, three steps require to pursue the process, State the Problem, Define the Criteria, and Define the Alternatives.

In the study, the problem was to identify which among the districts of Eskişehir Province are highly prone to Earthquake namely: Odunpazarı, Tepebaşı, Alpu, Beylikova, Çifteler, Günyüzü, Han, İnönü, Mahmudiye, Mihalgazi, Mihalıççık, Sarıcakaya, Seyitgazi, and Sivrihisar.

The criteria for the study were the geological elements Fault Line, Epicenter, and Lithology that are considered to cause or contribute to earthquake occurrence.

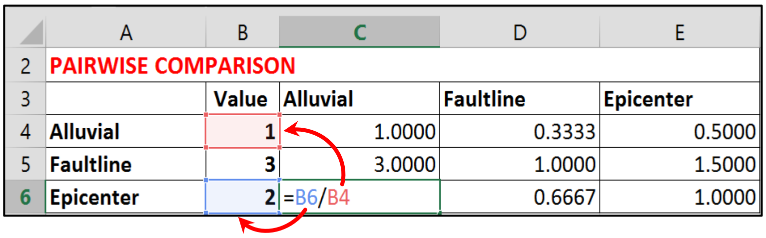
The alternative of the study was the districts of Eskişehir Province that may be disrupted by an earthquake if it occurs, namely: Odunpazarı, Tepebaşı, Alpu, Beylikova, Çifteler, Günyüzü, Han, İnönü, Mahmudiye, Mihalgazi, Mihalıççık, Sarıcakaya, Seyitgazi, and Sivrihisar.

The AHP can be performed in three simple phases:

1. *Identify the weight value or priority scale of the criteria:* Weight value can be acquired depends on the type of criteria, if the criteria have a number values, it goes directly to pairwise comparison and calculates its eigenvector but if the criteria do not have number value, assigning of value base on comparison judgment take place. The comparison judgments were better to rely on the experts to derive a reliable priority scale. On table 3, the assigned values for each criterion in every scenario serves as the priority scale for the whole process of AHP in the study.

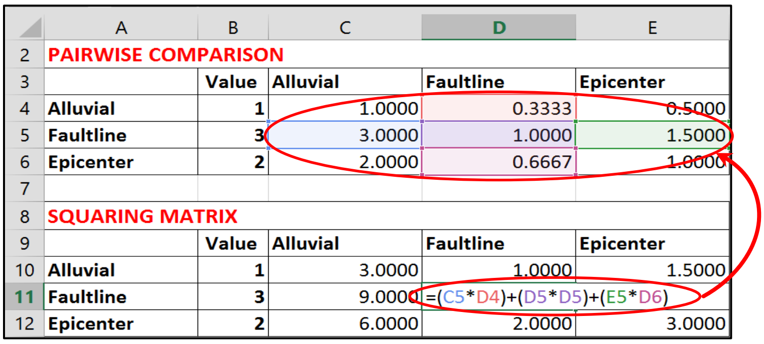
2. *Calculation of Eigenvector for the Alternatives:* It is the calculation of the relative weights, importance, or value of the factors, which are relevant to the problem in question (Konstantinos, n.d.). The value all alternatives from different criteria was calculated and acquired using GIS method. In getting the value of Eigenvector, the pairwise comparison must be calculated first. In pairwise comparison, the differences of each alternative were calculated by dividing all alternatives to each other (Figure 8). From the value of pairwise comparison, Eigenvector can be derived by making Square Matrix Algorithm, the summation of alternative values, and the normalization of the total summation of alternatives. Figure 9 shows the formula on how to calculate the square matrix from the Pairwise Comparison results. After the square matrix process, the value of each alternative was summed by row. And to normalize

the total summation of alternatives, it was divided by the total amount of all alternative summation as shown in figure 10. The normalized value was served as the value of the Eigenvector for each Alternative.



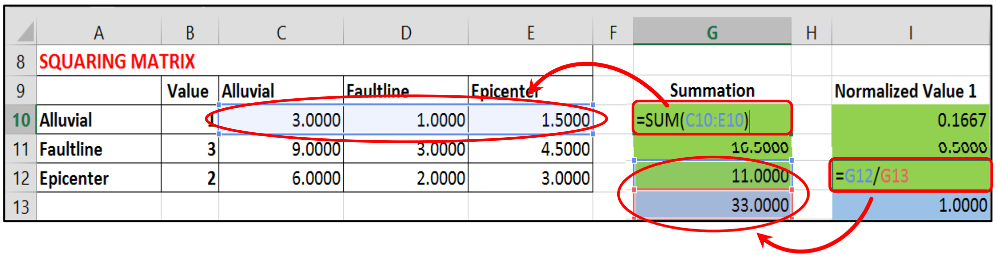
	A	B	C	D	E
2	PAIRWISE COMPARISON				
3		Value	Alluvial	Faultline	Epicenter
4	Alluvial	1	1.0000	0.3333	0.5000
5	Faultline	3	3.0000	1.0000	1.5000
6	Epicenter	2	=B6/B4	0.6667	1.0000

Figure 3.6. *Getting the differences of each criterion using pairwise comparison*



	A	B	C	D	E
2	PAIRWISE COMPARISON				
3		Value	Alluvial	Faultline	Epicenter
4	Alluvial	1	1.0000	0.3333	0.5000
5	Faultline	3	3.0000	1.0000	1.5000
6	Epicenter	2	2.0000	0.6667	1.0000
7					
8	SQUARING MATRIX				
9		Value	Alluvial	Faultline	Epicenter
10	Alluvial	1	3.0000	1.0000	1.5000
11	Faultline	3	9.0000	=(C5*D4)+(D5*D5)+(E5*D6)	
12	Epicenter	2	6.0000	2.0000	3.0000

Figure 3.7. *The formula of square matrix from the pairwise comparison results*



	A	B	C	D	E	F	G	H	I
8	SQUARING MATRIX								
9		Value	Alluvial	Faultline	Epicenter		Summation		Normalized Value 1
10	Alluvial	1	3.0000	1.0000	1.5000		=SUM(C10:E10)		0.1667
11	Faultline	3	9.0000	3.0000	4.5000		16.5000		0.5000
12	Epicenter	2	6.0000	2.0000	3.0000		11.0000		=G12/G13
13							33.0000		1.0000

Figure 3.8. *Summation of criteria and the normalization of total summation*

Two Eigenvectors are needed to test the reliability of the value acquired. In getting the second Eigenvector, the same process was applied on how the first Eigenvector was calculated, but the point the square matrix used was based on the First Eigenvector, not on the Pairwise Comparison. After getting the Second Eigenvector, the data acquired was verified its reliability using Consistency Ratio (Bunruamkaew, 2012). To do so, First Eigenvector was subtracted to the Second Eigenvector, and if the difference was zero or close to zero, the acquired data was consistent, but if higher the process must be repeated from the beginning until the consistency ration becomes equal to zero or close to zero. For the final Eigenvector value, the second value was used during the AHP Final Matrix.

3. *AHP Final Matrix:* The square matrix algorithm was applied using the Eigenvector value of both criteria and alternative to come up the final result on which district was highly prone from earthquake based from the three criteria, i.e., Earthquake, Epicenter, and Lithology. This process was done using the three scenarios, Scenario One, Two and Three.

3.1. Comparison of GIS and AHP Results

The comparison is a common research method with outstanding merits and with the widespread application (Azarian, 2011). GIS and AHP method are both reliable in their respective purposes; GIS is reliable in many aspects especially in Geologic Map Analyzation while the AHP is used in a wide range of decision making around the world (Nikjo et al., 2015). In connection, both were used in assessing the same problem in the study which was to identify which area of Eskişehir Province was highly prone to seismic activity.

To come up with a more powerful result, AHP method was used to support the GIS result by assessing their output from the three scenarios by identifying which has more similarity. Exact similarity of results from both methods was not expected because the two method has a hugely different way of assessing the data provided.

To identify which of the three scenarios of both method has similarity, the results of both method was calculated to get their percentage value. For AHP, the results value was simply multiplied by 100 to get its percentage value. However, it was found out that the GIS method was more complicated to get the percentage risk value because its results were in raster file and in order to get the risk percentage of seismicity, the cell size of "Zone One Area" was divided by the total cell size of its particular district and then normalized each district percentage from the total value of all district percentage. After normalization, the result value was multiplied by 100 to get the final percentage risk value. To see the graphical similarities, column chart was made based on the percentage value of each result from both method.

4. GEOLOGY

The geological condition of a particular area is one significant factor to consider in assessing any natural calamity such as earthquake, flood, drought, landslide, strong wind, snowstorm, mudslide, and etc. (Tyrologou et al., 2015). According to the study of Kaptan (2015), the geological condition of an area is important in assessing the seismic risk in the area of his study. There were several studies conducted on seismic risk assessment and used different types of geological conditions such as seismic hazard level, active faults, landslides, reservoirs, and rock slides that can be used as the geological factors during the assessment. However, in the study, the researcher focused only on three types of the geological element which are the Lithology, Fault Lines, and Epicenters within the vicinity of Eskişehir Province.

4.1. Lithology

Based on the result of the study of Göncüoğlu (2010), entitled "Introduction to the Geology of Turkey: Geodynamic Evolution of the Pre-Alpine and Alpine Terranes", it was pointed out that the Turkish orogenic collage can be separated into a number of Alpine tectonostratigraphic units or terranes, which were formed in a wide range of tectonic settings, including active and passive continental margins, rifts, arc and suture complexes, which were related to the opening and closure of various neotethyan oceanic branches (Göncüoğlu, 2010). In the study, however, only the Alluvial Deposits were considered as highly prone to seismic risk in the analysis because of soil characteristic of Eskişehir Province. The possibility of higher amplification in alluvium area is much higher compared to another lithological type in the area. It is certain that the possible damage and loss of life triggered by earthquakes are more concentrated in residential areas underlain by soft soils (Borcherdt, 1994).

The Geological Map of Turkey from MTA showed that the different categories of lithology in the whole country. Figure 11 shows the lithology in the province of Ankara and Eskişehir. This map was retrieved from the same geological map from MTA. The map has a scale of 1:500.000.

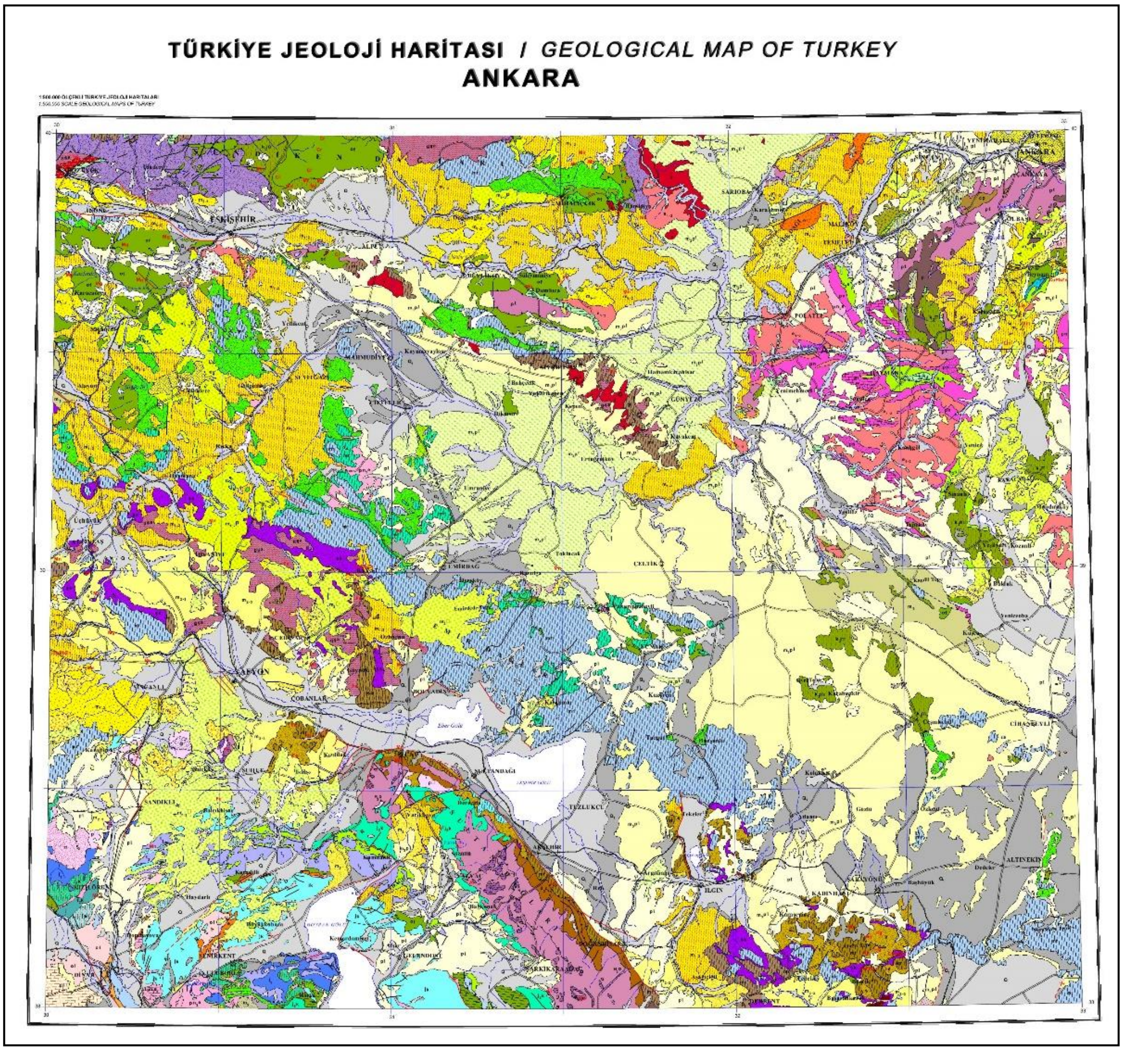


Figure 4.1. *Geological map of Ankara including the province of Eskişehir* (http - 3)

4.2. Fault Line

Turkey is located on the two major strike-slip fault zones are located, the North Anatolian Fault (NAF) and the East Anatolian Fault (EAF). The NAF is one of the most active fault lines in the world and also one of the most extensive fault lines with 1,199 km long, nearly the same length with the San Andreas Fault in California (Mekik et al., 2013). The country is within the compound zone of collision between the Eurasian Plate and both the African and Arabian Plates (Westaway et al., 2008).

Aside from the two major fault line in the country, different types of small fault lines are also situated in various provinces. Eskişehir is one province of Turkey with a number of the fault line that made the province suffer from the earthquake in the year 1956 (Orhan et al., 2007). Fault Lines are distributed in a different district of Eskişehir, the district of Tepebaşı has the longest fault line in the district with 192.7 km and Beylikova has the shortest which only has 0.7 km of fault lines. The total summation of fault line from the fourteen districts of the province was 1,046 km, but among all the fault line existing in the area, İnönü- Eskişehir fault line is the most active (MTA, 2017). "The İnönü- Eskişehir Fault System (IEFS) exhibits WNW−ESE striking Right-lateral strike-slip character with a normal component that extends from Uludağ (Bursa) in the west to Sivrihisar (Eskişehir) in the east and separates the west Anatolian extensional region from the central Anatolia to the northeast." (Selçuk et al., 2016). It is comprised of E−W and NW−SE trending fault sets and segments that made potential in producing devastating seismic activity.

4.3. Epicenter

The epicenter is a single point location on the earth surface, under it is the focus or the hypocenter where the earthquake rupture occurs (Bergman, 2016). In every single Epicenter, it must contain earthquake information such as the Magnitude value, Latitude, and Longitude, Date and Time occurred and other valuable data. From the data of earthquake epicenters, the effect of previews earthquake in the area can be analyzed base on the magnitude value using distinct tools of GIS.

In assessing a seismic risk, epicenter or earthquake history of an area is very useful in determining the particular area with a high value of risk including the other geological features such as Lithology and Fault Lines (Kanaori, 2000). In the Seismic Risk Map of Eskişehir produced by AFAD, Epicenters are one of the criteria used to assess the hazard in the area (Figure 12).

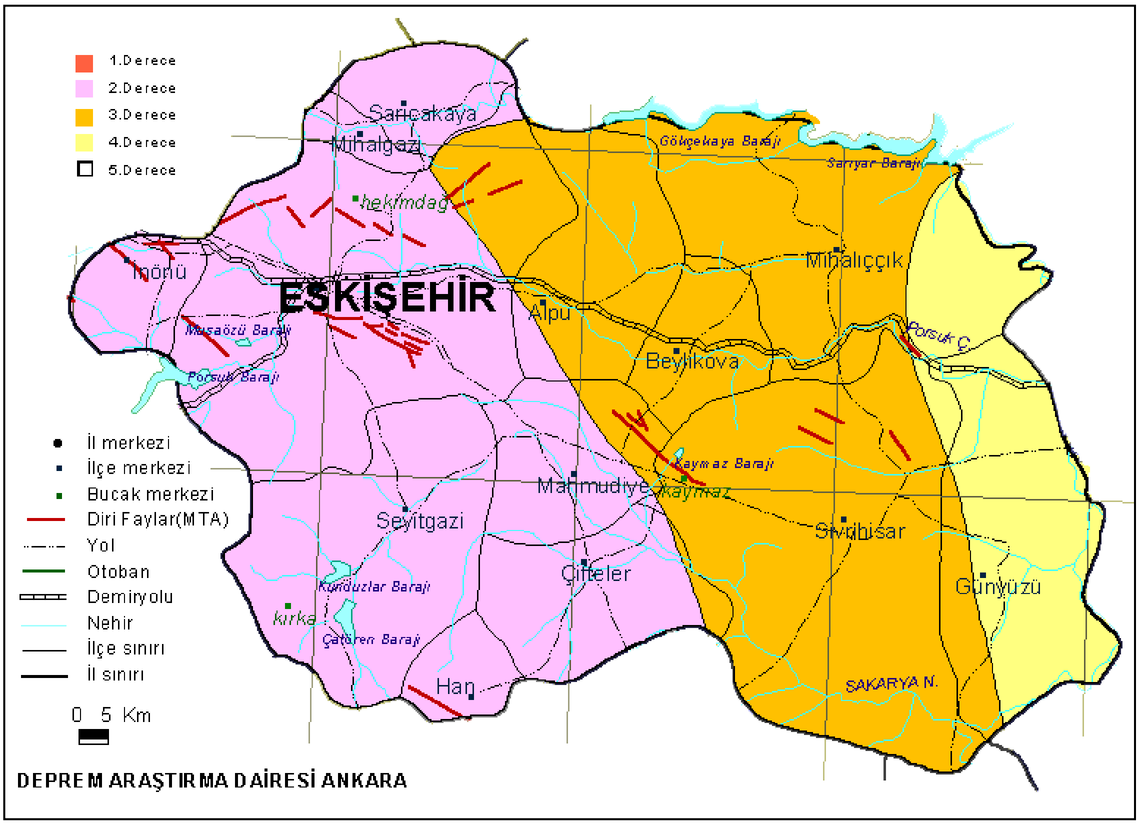


Figure 4.2. *Earthquake zoning map of Eskişehir from the official website of Disaster and Emergency Management of Turkey (AFAD, 1996)*

5. ANALYSIS

In this chapter, the procedures on how the Seismic Risk Map based on GIS and the risk order of seismic in each district of Eskişehir based from AHP were discussed. For the Epicenter, the IDW Interpolation was used to analyze the range effect of each earthquake data available in the area. As discussed in Chapter III, the lithological type of Eskişehir Province was first digitized to transform the raster map into a vector map and reclassify to assigned new values for each class. Likewise, the Fault Line was also digitized to become vector data and assigned five buffer zone using the Multiple Buffer Tool.

In getting the AHP result, three steps were performed. First, the eigenvector of criteria using the defined weight from the three scenarios were computed. Second, the eigenvector of alternatives from the three geological elements was calculated. And third, the Risk effect from the eigenvector of both criteria and alternative using Square Matrix Algorithm were calculated.

To support the result of GIS by the AHP, the similarity result of both methods from each scenario were analyzed by putting the result into Column Graph to get their graphical resemblance.

5.1. GIS Tools Analysis

GIS is a powerful method that uses several types of tools for different analysis. In the study, there were three types of tools used to come up the final output, such as IDW Interpolation, Multiple Fault Buffering, and Weighted Overlay. The IDW was employed to analyze the range effect of each epicenter's magnitude in the study area. For the Fault Line, Multiple Buffer Tool was used in assigning five different buffer zones around every fault lines. Weighted Overlay was used to merge the raster map of the three geological elements to produce a single map that shows the area with extremely high risk. The result will depend on the weight value assigned to each geological elements.

5.1.1. Application of Inverse Distance Weighting Interpolation

The IDW Interpolation was the tool used to interpolate the magnitude value of each earthquake recorded in the province of Eskişehir. Earthquake epicenter or the Earthquake catalog was downloaded from the official website of Kandili Rasathanesi, Deprem Arastirma Esntitusu (http://udim.koeri). To get the exact data, a required input is needed to start the download such as the coordinate of the study area and the time frame of the data needed.

And after the earthquake's data was downloaded, it was imported to the GIS software as a delimited text layer. After the transfer of data, it became a point shapefile, and each point locations were based on the coordinate data which was entered during the importing process. The point shapefile will serve as the Epicenter of the earthquake catalog. After the data was imported as point shapefile, the IDW Interpolation started by identifying the Z value field from the data table of the earthquake, which was the magnitude of the earthquake. From the data table, there were six types of magnitude value in every earthquake record, each of it was recorded from a different seismograph or different procedure. However, the study used the biggest magnitude value in specified magnitude values which was in the xM data field.

As high-resolution raster, the smallest the cell size, the finest the data output; (ESRI, 2008) therefore, cell size (X, Y) 0.001, 0.001 was used as the cell size of each map produced in the study. During the interpolation, selection tool was used for the number of data that needs to be interpolated in order to determine and know the exact number of data. There was a total of 646 earthquakes recorded from 1900 to 2017 within the perimeter of Eskişehir Province (Koeri, 2017).

The result of IDW Interpolation of the previews earthquake in the study area showed a different risk degree in the area. The image was reclassified into five different classes wherein each class indicates a level of risk of the previous earthquake. This indicates that if the earthquake will happen again in the same area with the same magnitude, the area in red colors will be a highly prone from seismic risk and the green was in the very least risk (Figure 13).

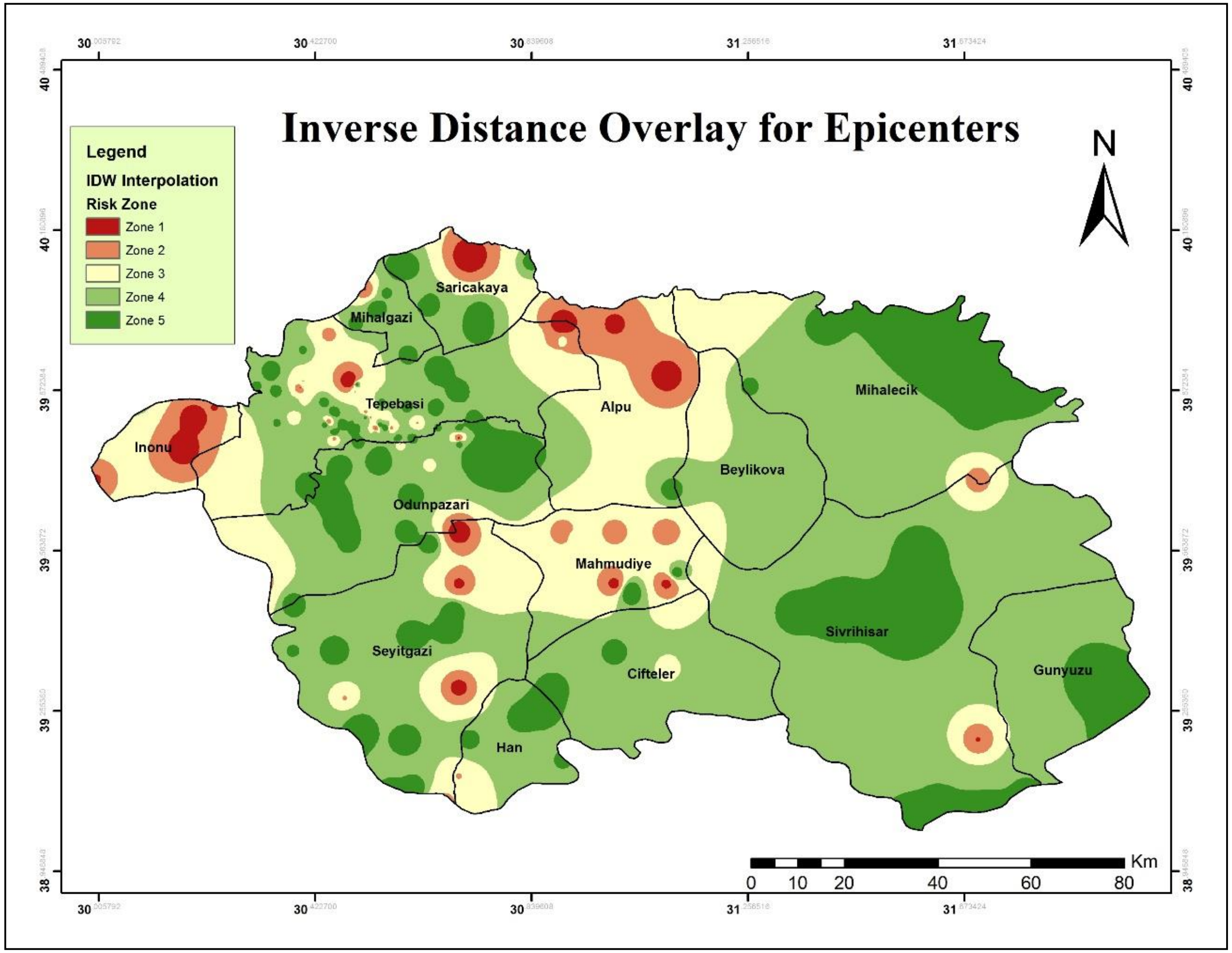


Figure 5.1. *Reclassified map of Inverse Distance Weighted Interpolation from earthquake epicenter of Eskişehir Province*

5.1.2. Application of multiple ring buffer

The Fault Line data in the study was used as the most influential geological element that causes an earthquake in the Eskişehir Province due to most earthquake often occurs along geologic faults (Bolt, 2018). This data was downloaded from the official website of MTA which was the same source of the Lithological map of the province. The data was also retrieved as WMTS file and digitized using polyline shapefile.

There were five different zones set around every fault line. The first zone was five kilometers away from the fault line which has the extremely high risk. The second zone was ten kilometers, the third zone was fifteen kilometers, the fourth zone was twenty kilometers, and the fifth zone was more than twenty kilometers which were the very least from risk. (Table 2). To define the different zones around the fault lines, Multiple Buffer Tool was used.

After the buffering analysis, vector to raster tool was used to convert the fault line zone vector data into raster data. And after the conversion was finished, the five zones was reclassified and value levels were changed into 1 to 5 value; this value indicates the risk degree of each buffer zone which was used during the weighted overlay analysis.

The result of the fault buffering showed that almost 50% of the area was covered with the first zone or the extremely high-risk zone. The most affected areas were from the north going to the west district such as the Sarıcakaya, Mihalgazi, Tepebaşı, and İnönü. (Figure 14).

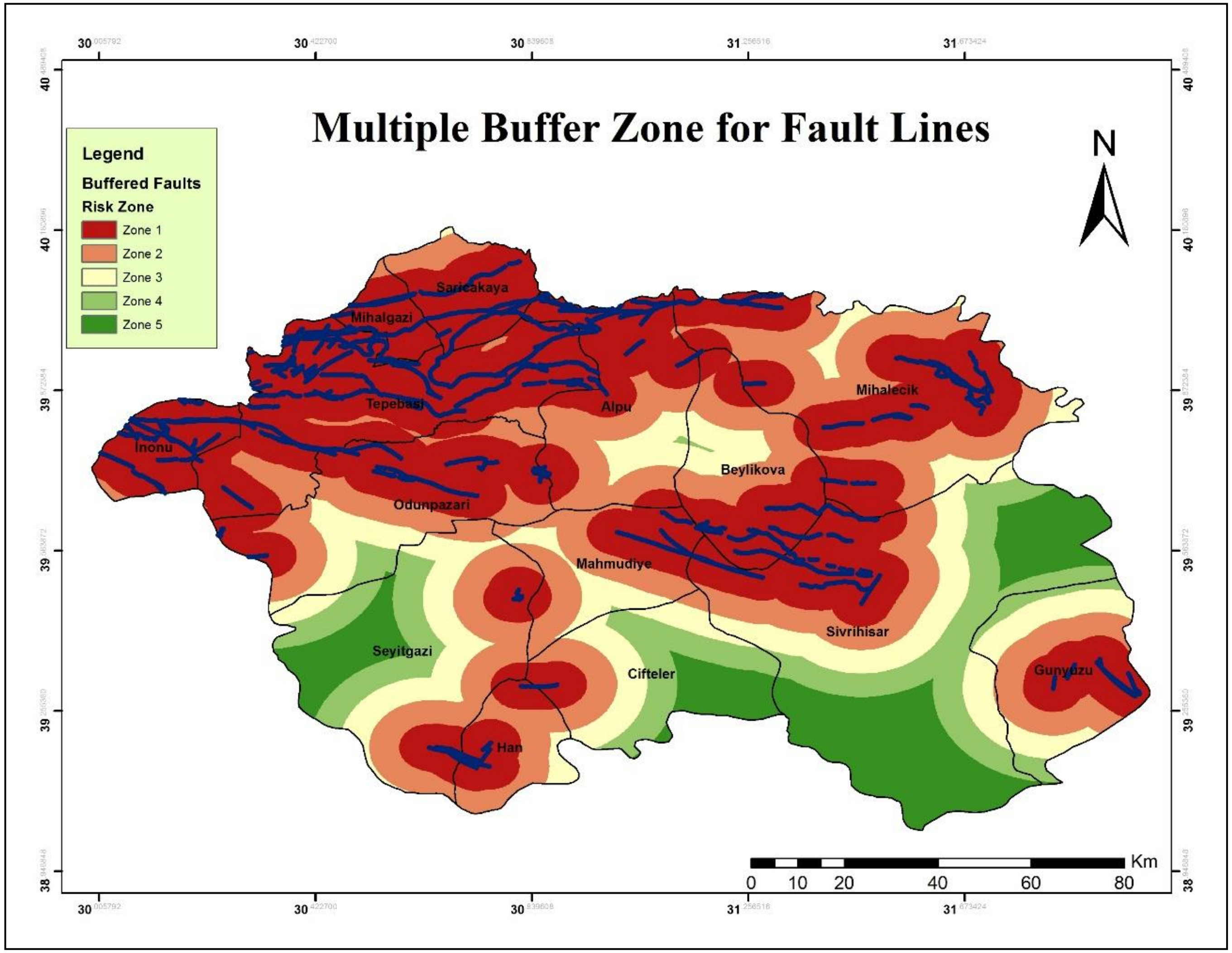


Figure 5.2. *Reclassification result of multiple ring buffer from fault lines*

5.1.3. Application of weighted overlay

The Weighted Overlay Analysis tool was used to analyze the raster risk map of the three geological elements (Epicenter, Lithology, and Fault Line) into single risk map using their common measurement scale 1 to 5 and criteria weights according to their importance. The criteria weight was defined in three scenarios. First, all the three criteria have equal weight value according to earthquake risk. In the second scenario, Fault Lines has grade 3, Epicenter has grade 2 and then Lithology has grade 1. The third scenario, Fault Line has grade 3, Lithology has grade 2 and Epicenter has grade 1. (Table 3).

There were three Seismic Risk Map results in this analysis. Each result has different weight values for the criteria that were calculated in AHP method; the result served as the influence value of the weighted overlay. The sum influence of all criteria in weighted overlay must be in a total of 100. Therefore, to use the criteria weight value from AHP, it requires calculating the percentage value of each criterion from the three scenarios (Table 4, 5, and 6).

The analysis was started by selecting the reclassified raster data of the three geological elements. When the selection process was done, the value from Scenario One was used as the influence value of the three geological elements for the first Seismic Risk Map. The same process was used for scenario two and the scenario three on how the Risk map was analyzed in scenario One using the weighted overlay.

The result of Scenario One showed that only a small area of Extremely High Risk is located in the district of İnönü. The district of Tepebaşı, Alpu, and Seyitgazi also have the extremely high-risk area but in a smaller amount. The majority area of the province was under zone 3 (Moderate Risk) and zone 4 (Low Risk) (Figure 15).

The result of Scenario Two showed that only a few districts have the Extremely High-Risk area, but mostly covered by Zone 2 (High Risk) and Zone 3 (Moderate Risk). The most extensive risk zone is the İnönü same as in the result of scenario one, while the Tepebaşı, Alpu, and Mahmudiye have a minimum area of risk. However, these areas were still considered as an extremely high risk to settle in. (Figure 16).

The result of Scenario Three showed a larger area of extremely high risk compared to the results of other scenarios. This result showed that it was riskier in the area of Tepebaşı consist of largest Zone 1 area compare to other districts. Although this map result showed a larger area of Zone 1 compared to another map result, still the whole province was mostly covered by Zone 3 which was moderate from earthquake risk. (Figure 17).

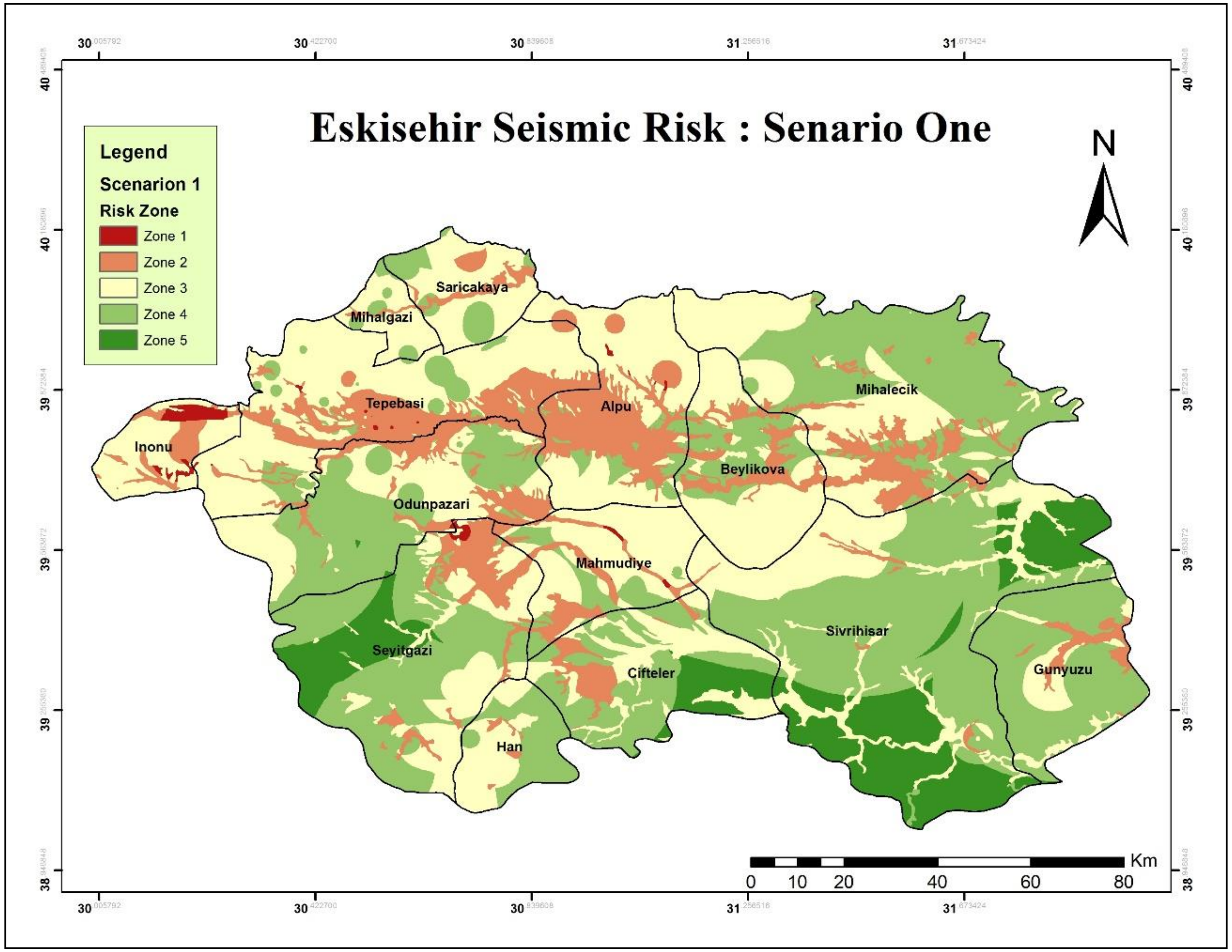


Figure 5.3. *Seismic risk map using scenario one weights value*

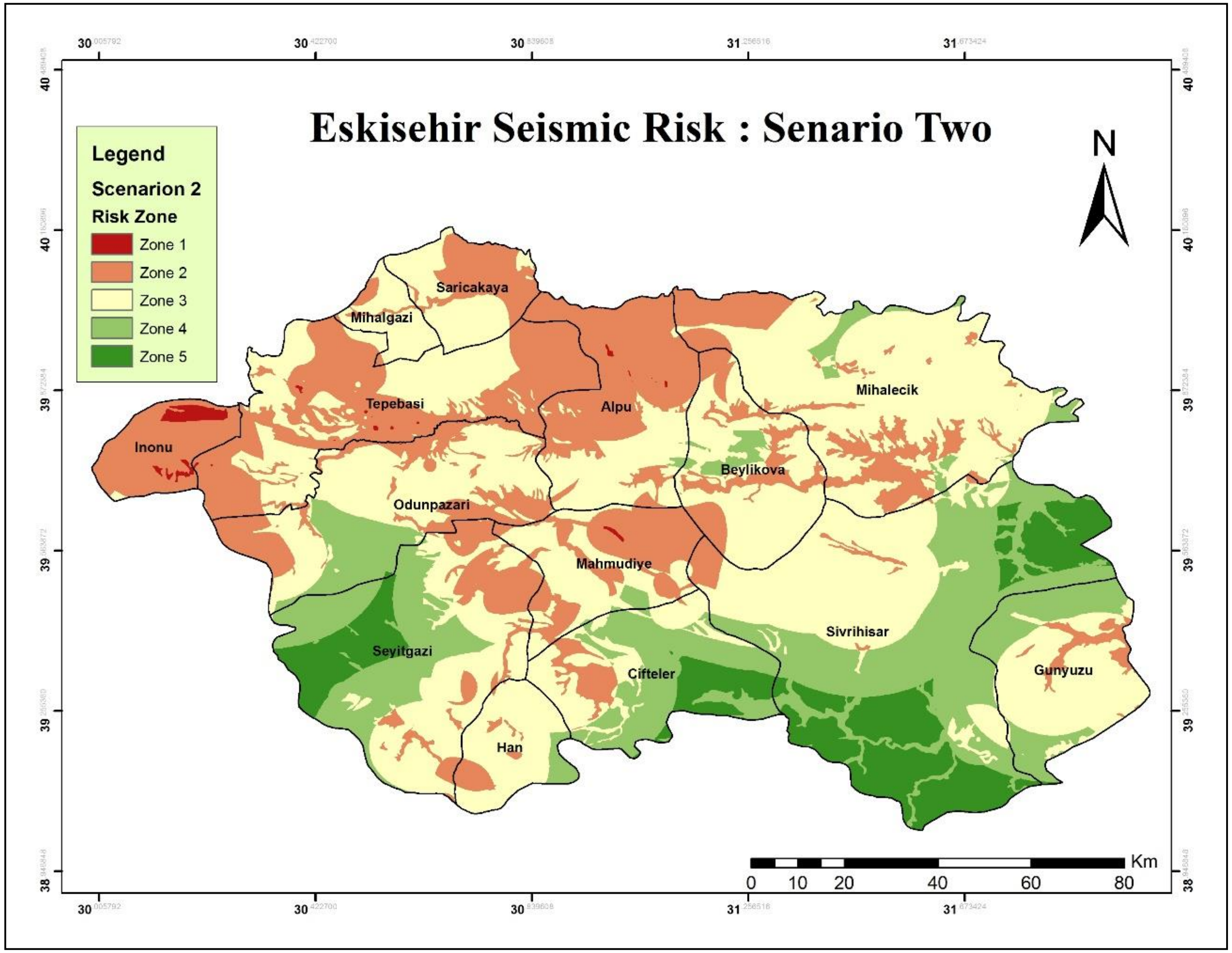


Figure 5.4. *Seismic risk map using scenario two weights value*

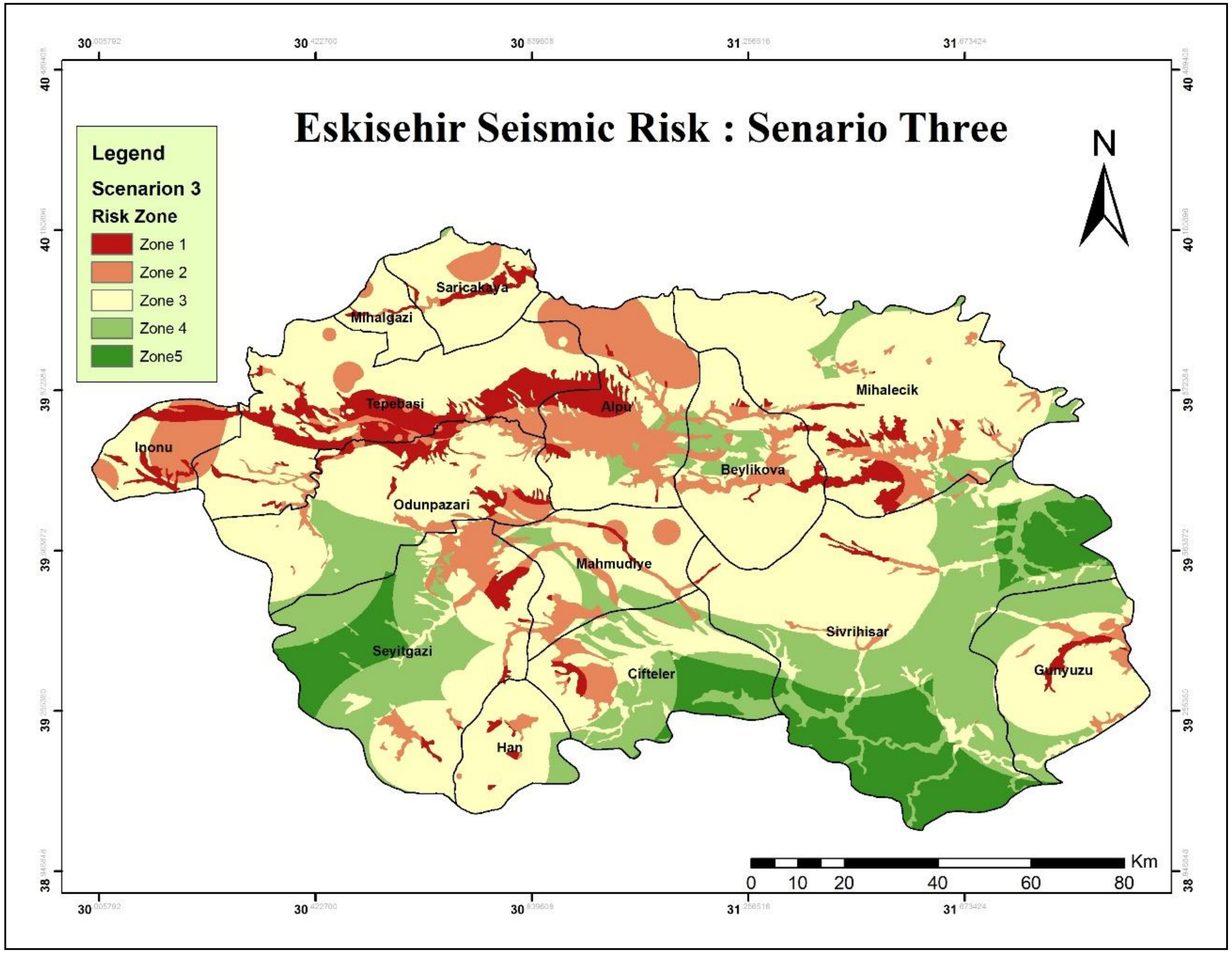


Figure 5.5. *Seismic risk map using scenario three weights value*

5.2. Analytic Hierarchy Process (AHP)

This method is widely used in a broad range of decision making such as in business, healthcare, education, government, industry, and disaster management (Lepetu, 2012). In the study, the AHP method was used to identify which district of Eskişehir Province was at the highest risk from an earthquake. Based on the results, it helped the study to decide which among the GIS results were more appropriate for the final result.

In this method, there were three simple phases to be implemented to come up the final result. The implemented phases are 1) Calculation of Criteria Weights (Eigenvector), 2) Calculation of Alternative Weights (Eigenvector), and 3) Calculation of the final weights of Seismic Risk using the Criteria weights and Alternative Weights (The Analytic Sciences Corporation, 1996).

5.2.1. Computation of criteria weights

Before the computation of criteria weights, each criterion (the geological elements) were assigned with its importance value. The importance value determines which criterion has a higher source of the earthquake. The value used was either 1, 2, or 3, value 3 as the highest importance value and 1 as the lowest important value. The value used for the criteria was derived from "Engineering Judgement".

For scenario one, the importance or weight value used for the three criteria was 1 or equal value. It means that there was no criterion is higher than other criteria.

In getting the weight value of each criterion, there were few steps done. First was to compare the value of each criterion to another criterion by using the Pairwise comparison. In pairwise comparison, the criteria were compared by dividing the value of one criterion to another value (Figure 7). The second was to get the first Eigenvector by making square matrix base from the Pairwise Comparison (Figure 8). When the square matrix was done, the value of criteria in a row was added, and the result of each criteria value was added again to be used for the normalization process. The result of normalization served as the value of the first Eigenvector (Figure 9). The third was to calculate the second Eigenvector. And to get its value, the same process on how the first eigenvector was calculated but the square matrix was not based from the pairwise comparison, rather it was based from the table of the first eigenvector. The two eigenvectors were subtracted to each other to confirm its consistency. When the difference between these sums in two consecutive calculations is smaller than a prescribed value; it signifies that the value was consistent. The value of the Second Eigenvector serves as the final Criteria Weights in Scenario One (Table 4).

The result of scenario one showed that all the criteria have an equal weight value. The Alluvium, Fault Line, and Epicenter have the same value of 0.3333 with a 33%.

Table 5.1. *Criteria weight value from scenario one including its percentage value*

Scenario One		
Criteria	**AHP Weights**	**GIS Weights**
Alluvium	0.3333	33
Fault Line	0.3333	33
Epicenter	0.3333	33

For Scenario Two, the importance value used was 1 for Alluvium, 2 for Epicenter, and 3 for Fault Line. The value assignment means that the criteria with the highest importance among other were the Fault Line and the least was the Epicenter. These criteria were calculated their weights by the same process on how the Scenario One was calculated.

The result of Scenario Two showed that the three criteria have different weights value. Alluvium has the least value of 0.1667 or 17%, a fault line has the highest value of 0.5000 or 50% and the Epicenter has 0.3333 or 33 (Table 5).

Table 5.2. *Criteria weight value from scenario two including its percentage value*

Scenario Two		
Criteria	**AHP Weights**	**GIS Weights**
Alluvium	0.1667	17
Fault Line	0.5000	50
Epicenter	0.3333	33

For Scenario Three, the importance value used was 1 for Epicenter, 2 for Alluvium, and 3 for Fault Line. The fault line remains the highest importance value because of its apparent influence to an earthquake (Bolt, 2018). The influence value for Alluvium and Epicenter were exchanged to have a difference from the Scenario Two. The same process of calculation was applied to get the appropriate results.

The result showed that the three criteria have different values like in the Scenario Two. The Fault Line remains the highest with a value of 0.5000 or 50%. Alluvium has 0.3333 or 33% while Epicenter with a value of 0.1667 or 17% which was the least among the other criteria. (Table 6).

Table 5.3. *Criteria weight value from scenario three including its percentage value*

Scenario Three		
Criteria	**AHP Weights**	**GIS Weights**
Alluvium	0.3333	33
Fault Line	0.5000	50
Epicenter	0.1667	17

5.2.2. Computation of alternative weights

Alternatives are the different choices of the decision making. In the study, fourteen districts of Eskişehir Province was considered as the options, which among them has the highest risk from earthquake based on the three geological elements.

All the data of each alternative from the three geological elements were processed and calculated in GIS software. The data of all district from Fault Line was calculated by clipping the entire fault line base from its district location. All fault line was named base from its district location and merge into one single file. Calculate Geometry tool was used to acquire the length value of each fault line in every district.

The data were transferred to Microsoft Excel to start the computation of Alternative Weight Value or the Eigenvector. The same process on how the Criteria Weight was calculated by using Pairwise Comparison, Square Matrix of the first Eigenvector and second Eigenvector, and the computation of Consistency Ratio.

The result showed that the weight value of Tepebaşı District was far higher than the others districts because of the existing fault line in the area which has a total length of 332.609 km with an equivalent weight value of 0.3146. On the other hand, the very least computation of seismic risk was Çifteler which has only 3.666 km of the fault line and has 0.0038 weight value (Table 7).

Table 5.4. *Alternatives weight value according to fault line*

FAULT LINE WEIGHT VALUES	
Alternatives	**Weights**
Odunpazarı	0.0650
Tepebaşı	0.3146
Alpu	0.0886
Beylikova	0.0482
Çifteler	0.0038
Günyüzü	0.0275
Han	0.0182
İnönü	0.0950
Mahmudiye	0.0263
Mihalgazi	0.0413
Mihalıççık	0.1099
Sarıcakaya	0.0617
Seyitgazi	0.0170
Sivrihisar	0.0828

For the Alluvium of the study area, the data for each district was acquired by calculating the area of each alluvium in every district using the same tool from previous which were the Calculate Geometry. Before calculating the area, the same process from previous calculation was applied which was clipping the alluvium spatial data based on the area of each district.

The result shows that the district Çifteler and Alpu have the highest weight value even though they have a smaller area of alluvium compare to Tepebaşı, and Sivrihisar. The districts of Alpu and Çifteler are also smaller than the district of Tepebaşı and Sivrihisar based on the total area, Alpu has 934.87 km^2 and 898.68 km^2 for Çifteler. The weight value of the two districts become the highest because when the average area of alluvium was calculated based on its respective district, the order of risk changed. Alpu has 327.09 km^2 of alluvium area with a risk or weight value of 14%. Çifteler District is also much smaller compared to other districts in the province with only 898.68 km^2 of the area but the Alluvium area is quite large that make its risk value higher as well. The districts of Tepebaşı, Sivrihisar, and Odunpazarı have a large alluvium in their locations but the average of risk is less because of its extensive district area (Table 8).

Table 5.5. *Alternatives weight value according to alluvium*

LITHOLOGY (Alluvium) WEIGHT VALUES	
Alternatives	**Weights**
Odunpazarı	0.0713
Tepebaşı	0.1059
Alpu	0.1356
Beylikova	0.0825
Çifteler	0.1386
Günyüzü	0.0539
Han	0.0226
İnönü	0.0810
Mahmudiye	0.0753
Mihalgazi	0.0217
Mihalıççık	0.0575
Sarıcakaya	0.0389
Seyitgazi	0.0652
Sivrihisar	0.0498

The number of the epicenter in each district was counted using Select by Location tool. This tool selects data based on the location of another data. Using this tool, all the epicenter within a certain district were selected, and the number of selected data can be seen in the attribute table in GIS. These numbers were recorded directly in Microsoft Excel with its corresponding district to start the Weight Calculation.

The result showed that the Tepebaşı and Odunpazarı have the highest weight value of 0.3816 and 0.1717 while the lowest was Beylikova and Günyüzü with a weight value of 0.0002 and 0.0128 respectively. The Tepebaşı district with 58 epicenters became the district with the highest risk from Epicenters, while the Beylikova has zero earthquake history from 1900 to 2017 (Keori, 2017). Since the common source of an earthquake around the globe is the fault line, (Bolt, 2018) the differences of districts data from earthquake history were quite far due to the heavy existence of fault line in some district like Tepebaşı and Odunpazarı (Table 9).

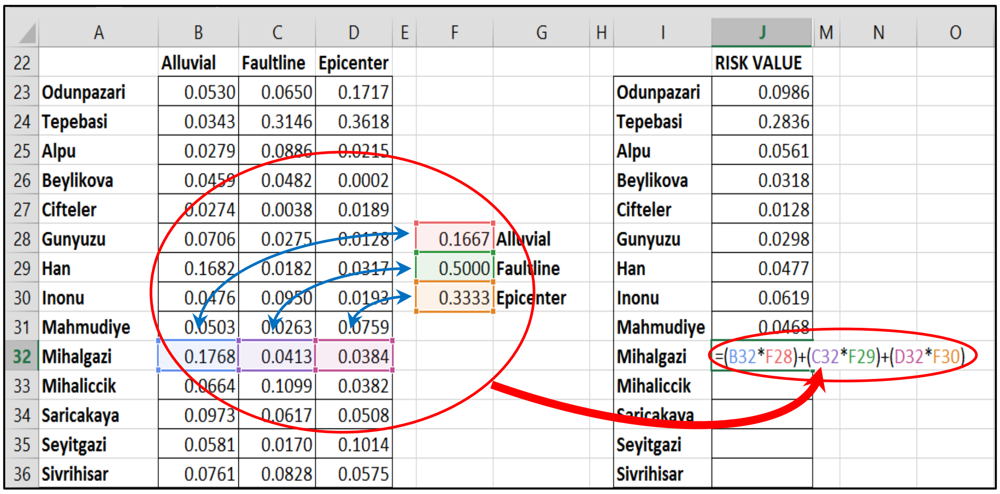
Table 5.6. *Alternatives weight value according to epicenter*

EPICENTER WEIGHT VALUES	
Alternatives	**Weights**
Odunpazarı	0.1717
Tepebaşı	0.3618
Alpu	0.0215
Beylikova	0.0002
Çifteler	0.0189
Günyüzü	0.0128
Han	0.0317
İnönü	0.0193
Mahmudiye	0.0759
Mihalgazi	0.0384
Mihalıççık	0.0382
Sarıcakaya	0.0508
Seyitgazi	0.1014
Sivrihisar	0.0575

5.2.3. Computation of AHP final result

This final computation provided the final weight value or the Risk Value of each district from the three geological elements or criteria base from the Three Scenario. The three scenario consists of Scenario One with an equal value for all criteria, Scenario Two with highest importance value for fault line and least value for the Alluvium, and Scenario Three that the fault line was still with the highest value and the least value was Epicenter (Table 3).

To get the final result from AHP, each criteria value from the three scenarios were calculated with the three alternative value of the geological elements using the square matrix algorithm. Each scenario provided its risk result based on seismicity and was used during the verification of final result of the study. In square matrix algorithm, the weight value of each Alternative was multiplied by the weight value of Criteria and then added with the other geological element. The result value from each district was the risk combination of the three geological elements (Figure 18).



	A	B	C	D	E	F	G	H	I	J
22		Alluvial	Faultline	Epicenter						RISK VALUE
23	Odunpazari	0.0530	0.0650	0.1717					Odunpazari	0.0986
24	Tepebasi	0.0343	0.3146	0.3618					Tepebasi	0.2836
25	Alpu	0.0279	0.0886	0.0215					Alpu	0.0561
26	Beylikova	0.0459	0.0482	0.0002					Beylikova	0.0318
27	Cifteler	0.0274	0.0038	0.0189					Cifteler	0.0128
28	Gunyuzu	0.0706	0.0275	0.0128		0.1667	Alluvial		Gunyuzu	0.0298
29	Han	0.1682	0.0182	0.0317		0.5000	Faultline		Han	0.0477
30	Inonu	0.0476	0.0950	0.0193		0.3333	Epicenter		Inonu	0.0619
31	Mahmudiye	0.0503	0.0263	0.0759					Mahmudiye	0.0468
32	Mihalgazi	0.1768	0.0413	0.0384					Mihalgazi	=(B32*F28)+(C32*F29)+(D32*F30)
33	Mihaliccik	0.0664	0.1099	0.0382					Mihaliccik	
34	Saricakaya	0.0973	0.0617	0.0508					Saricakaya	
35	Seyitgazi	0.0581	0.0170	0.1014					Seyitgazi	
36	Sivrihisar	0.0761	0.0828	0.0575					Sivrihisar	

Figure 5.6. *Computation of AHP final result using square matrix algorithm*

The result of Scenario One showed that the top three district with highest Seismic risk were Tepebaşı with 0.2369, Odunpazarı with 0.0966 and Mihalgazi with 0.0855. These three has that the highest because of the presence of the geological elements in their respective area even though the entire geological element has equal weight values.

On the other hand, the top three districts with lowest Seismic risk were the Tepebaşı with 0.2608, Odunpazarı with 0.1027, and Alpu with 0.0819 weight value. These three districts are the safest from seismicity because of the least presence of the three geological elements in their areas (Table 10).

Table 5.7. *The AHP final result according to scenario one (From highest risk value to lowest)*

Scenario One for Seismic Risk	
Districts	**Risk Value**
Tepebaşı	0.2608
Odunpazarı	0.1027
Alpu	0.0819
Mihalıççık	0.0685
İnönü	0.0651
Sivrihisar	0.0634
Seyitgazi	0.0612
Mahmudiye	0.0592
Çifteler	0.0538
Sarıcakaya	0.0505
Beylikova	0.0436
Mihalgazi	0.0338
Günyüzü	0.0314
Han	0.0242

The result of AHP from Scenario Two showed that the top three districts with the highest risk from seismicity were Tepebaşı with 0.2955, Odunpazarı with 0.1016, and Mihalıççık with 0.0773. While the top three district with the lowest risk from seismicity were Han with 0.0234, Günyüzü with 0.0270, and Çifteler with 0.0313 (Figure 11).

Table 5.8. *The AHP final result according to scenario two (From highest risk value to lowest)*

Scenario Two for Seismic Risk	
Districts	**Risk Value**
Tepebaşı	0.2955
Odunpazarı	0.1016
Mihalıççık	0.0773
Alpu	0.0741
Sivrihisar	0.0242
İnönü	0.0674
Sarıcakaya	0.0543
Seyitgazi	0.0532
Mahmudiye	0.0510
Beylikova	0.0379
Mihalgazi	0.0371
Çifteler	0.0313
Günyüzü	0.0270
Han	0.0234

The result of AHP from Scenario Three shows that the top three district with the highest risk from seismicity were Tepebaşı with 0.2529, Alpu with 0.0931, and Odunpazarı with 0.0849. While the top three lowest were Han with 0.0219, Günyüzü with 0.0339, and Mihalgazi with 0.0343 (Table 12).

Table 12. *The AHP final result according to scenario three (From highest risk value to lowest)*

Scenario Three for Seismic Risk	
Districts	**Risk Value**
Tepebaşı	0.2529
Alpu	0.0931
Odunpazarı	0.0849
Mihalıççık	0.0805
İnönü	0.0777
Sivrihisar	0.0676
Sarıcakaya	0.0523
Beylikova	0.0516
Çifteler	0.0513
Mahmudiye	0.0509
Seyitgazi	0.0471
Mihalgazi	0.0343
Günyüzü	0.0339
Han	0.0219

5.3. Comparison of GIS and AHP Result

In this process, GIS method and AHP method were not compared not to determine which method is more suitable for seismic risk assessment. The comparison was done to determine which scenario or weight importance was the most appropriate to the three identified geological elements (criteria). Consistent with the discussion from the previous chapters, the importance weight of each geological element from each other was not known that is why the different weight importance in the three scenarios was used. At the same time, the process determined the final result of the study by finding the scenario with the similarity between the two methods.

The process was done by getting the percentage risk of seismicity from AHP and GIS results. For the AHP, the second Eigenvector value was just simply multiplied into 100 to get its percentage value, but in GIS, the result was in Raster file and to get the risk percentage, the three raster result of GIS was the clipped based from the area of the fourteen districts of Eskişehir Province. From the clipped raster map, Zone One Area was used since it has the extremely high-risk area set during the assessment. The cell size value of Zone One was divided by the total cell size of its corresponding district and then normalized by multiplying the risk value of each district with the overall risk value of all the districts. The same process on how normalization in AHP was calculated. The result was multiplied by 100 to get the Risk Percentage. When all the percentage value was calculated from both method, Column Chart was made based on the risk percentage result using the Microsoft Excel to the differences of each result from the two methods.

5.3.1. GIS and AHP results from scenario one

Scenario One result from both methods provides a far difference of column chart. In AHP, all the district has a different value of risk while the GIS showed that some of the districts were not having any sign of seismic risk according to the zone one. Only the districts of Odunpazarı, Tepebaşı, Alpu, İnönü, Mahmudiye, and Seyitgazi has a risk value and the rest were zero risks. İnönü has the highest value with 84% in GIS and Tepebaşı district in AHP with 26% risk (Figure 19).

5.3.2. GIS and AHP results from scenario two

The result of Scenario Two showed a lot of difference of result from both methods. In AHP, it showed that all the district has risk value due to the presence of three geological elements and the district with the highest risk was Tepebaşı compared to GIS result showed that only five out of fourteen districts had risk value and İnönü district has the highest value with 90% of Zone One area (Figure 20).

5.3.3. GIS and AHP results from scenario three

The Scenario Three showed that both results from two methods provide a risk value to all 14 districts. Some districts have the same value like the district of Odunpazarı, Alpu, Günyüzü, and Han but for another district like İnönü, Sivrihisar, Sarıcakaya, and Mahmudiye have a large difference risk percentage of 15%, 6%, 4%, and 4%, respectively. The rest of the districts have a minimal difference of 1% to 2% only. Both methods showed Tepebaşı district has the highest risk percentage, 25% from AHP and 23% from GIS. This result was somewhat closer compared to the result of Scenario One and Scenario Two in both methods (Figure 21).

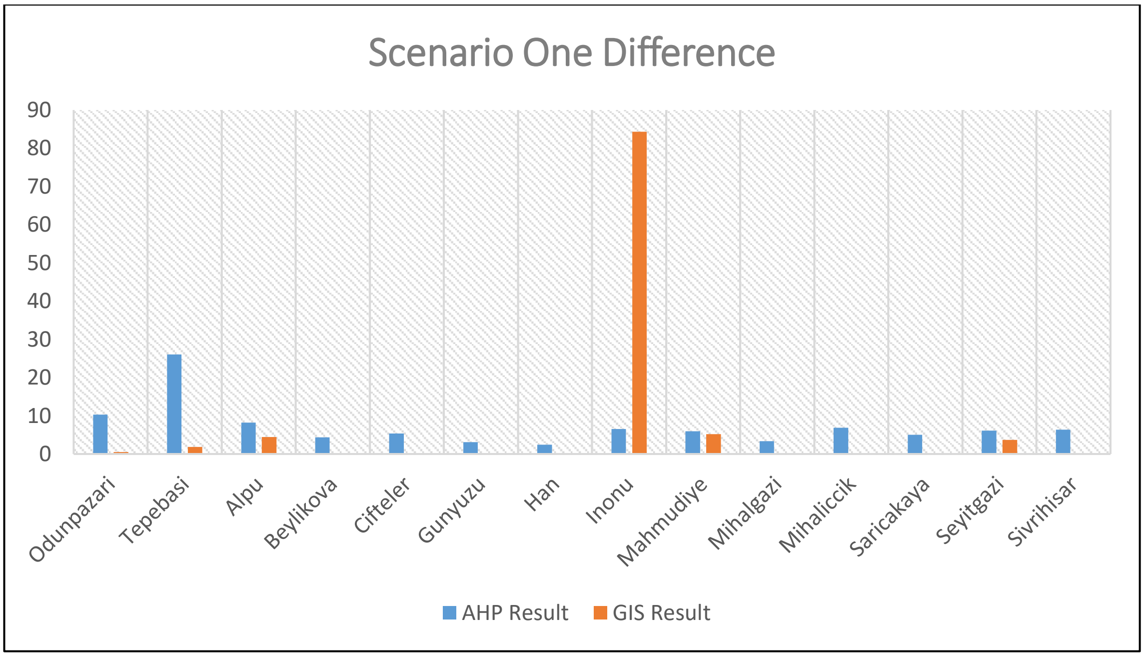


Figure 5.7. *AHP and GIS result from scenario one in column charts*

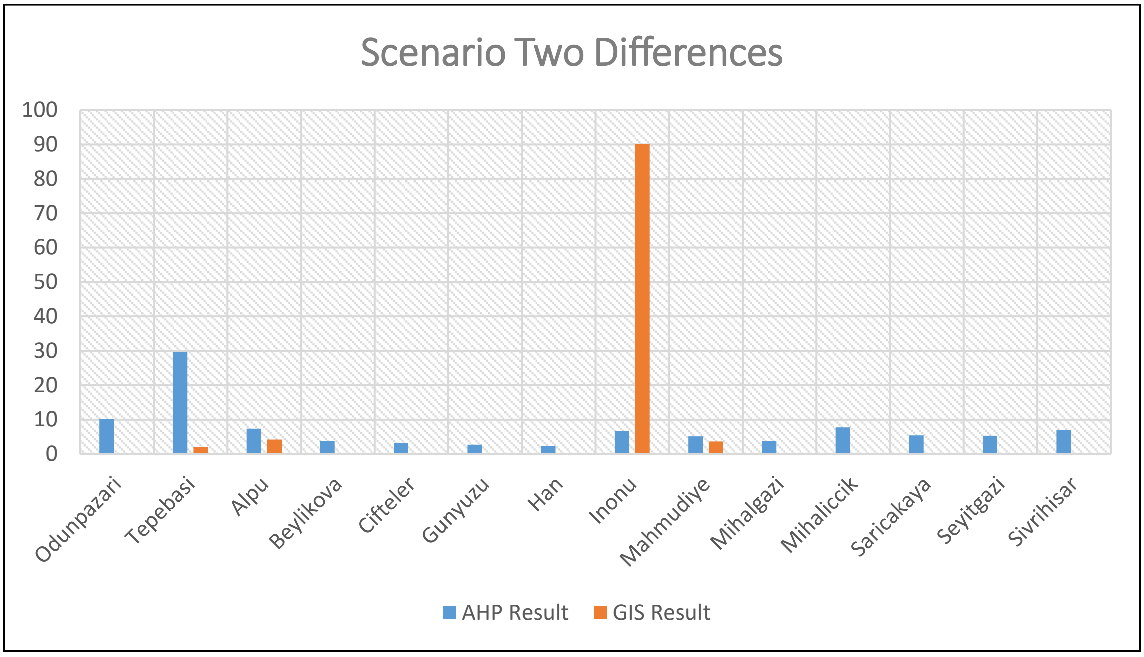


Figure 5.8. *AHP and GIS result from scenario two in column charts*

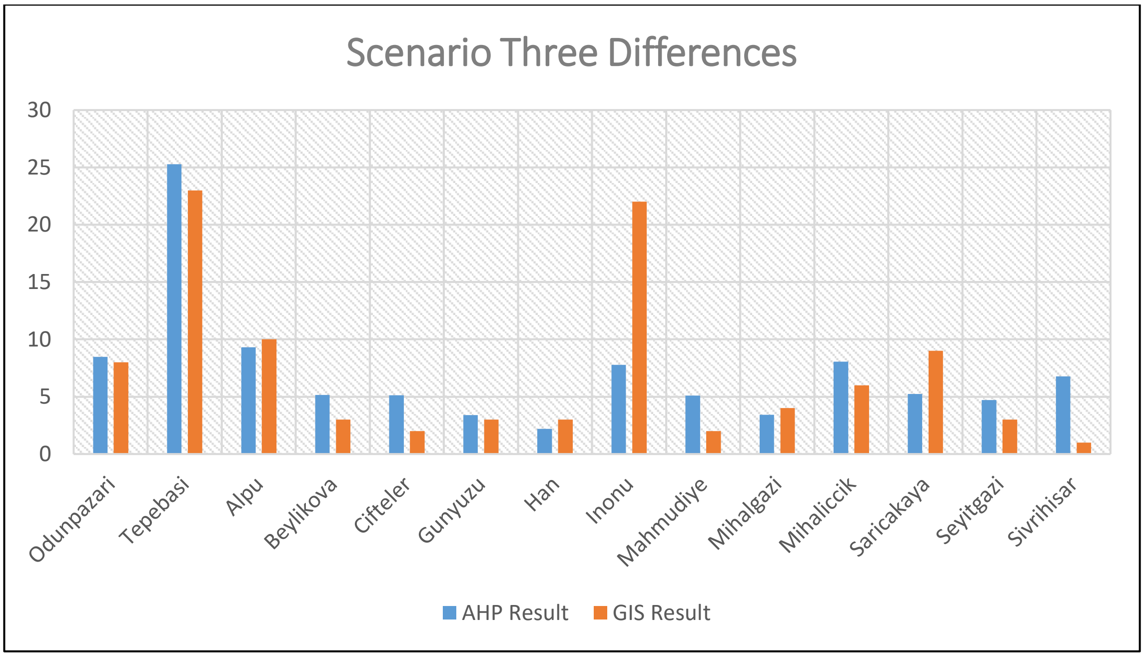


Figure 5.9. *AHP and GIS result from scenario three in column charts*

6. RESULTS AND DISCUSSIONS

In this chapter of the study, it focuses on the presentation of results and discussions of all analysis from the gathered data based on the defined problems. The order of discussion is according to the sequence of the questions from the Statement of the Problem.

The first question that the study sought out to answer is, “Which area is highly prone to earthquake risk regarding on lithology criterion?”

The figure result from GIS showed that alluvium lithology spreads out to all district of Eskişehir and based on the result of the lithology classifications, the district with the largest area of alluvium are Tepebaşı with 394 km^2, Sivrihisar with 359 km^2, Alpu with 327 km^2, and Çifteler with 322 km^2.

The Table 8 result from AHP showed that the districts with the higher risk from the soft ground are Çifteler and Alpu. If base on the size area of alluvium, the Tepebaşı and Sivrihisar have the highest risk because of their extensive area of alluvium. However, when the area of the districts was considered to get the average area of alluvium from its districts, the district of Çifteler and Alpu became the highest because of their smaller land area. Çifteler and Alpu are among the district with an area below 1000 km^2 in the province but with the highest risk percentage from soft ground, 13.86% for Çifteler district and 13.56% for Alpu district.

The second question that the study sought out to answer is, “Which area is highly prone to earthquake risk regarding on fault lines criterion?”

Based from the result of the GIS method, the study revealed that the northern part going to western part of Eskişehir Province has the Extremely High Risk according five kilometer buffer zone from fault line. The first five kilometer buffer zone almost covers the districts of Sarıcakaya with 11% of Zone One located in its area, Mihalgazi and Tepebaşı with 12%, and Inonu with 13%. Majority of the fault lines of the province are located in these district that makes them in highest risk regarding the fault line. The district of Mihaliccik and Han was small and with less fault line, but the buffer zone almost covers the whole district that makes them at high risk.

The result from AHP showed the districts with higher risk based on the length value of fault line situated in every area. Tepebaşı is the highest among all the district that has 333 km distributed fault line which is 31% higher compared to other districts. Mihalıççık has 115 km distributed fault line which is 11%, and İnönü has 103 km distributed fault line which is 10%. Compared to Tepebaşı, the two districts are three times less at risk. Tepebaşı is holding the highest value of risk because of the great number of fault lines in its area, unlike the other districts that have very less presence of fault lines.

The Third question in the study sought out to answer is, “Which area is highly prone to earthquake risk regarding on epicenters criterion?”

The result of GIS showed that the district of İnönü has 51% of Zone One located in its area, Sarıcakaya with 23%, and Alpu with 15% due to the magnitude value of earthquake occurred in the area from the past has much higher magnitude value than the other districts of the province. Tepebasi had several histories of an earthquake, but the analysis does not show a broader risk on its area because the majority of earthquake occurs in the area are below magnitude 4.0 which is considered not harmful to human life. As according to MMI and Richter Scale, magnitude 4.0 and below is not hazardous to human life since it can be felt only by a few persons at rest, and not on upper floors of buildings. This earthquake magnitude level are not even noticeable, and many people do not recognize it as an earthquake (Table 1).

The Table 9 result of AHP is based on the number of earthquake epicenter in the area. It showed that Tepebaşı has 36% risk that makes it the district with the highest risk, next is Odunpazarı with 17% and Seyitgazi with 10%. These three districts become highest compared to other districts because of the number of the epicenter in their area. The concerned districts recorded the following number of epicenters from 1900 to 2017: for Tepebaşı has 58 epicenters, Odunpazarı has 27 epicenters, and Seyitgazi has 19 epicenters. The Beylikova district has the very least number of epicenters as the district has no earthquake history since 1900 to 2017.

The fourth question that the study sought out to answer is, “Using the three scenarios, which area is highly prone to earthquake risk based on the three criteria?”

In Scenario 1 (Fault Line:1, Lithology: 1, Epicenter: 1), the GIS method showed that the district of İnönü has the highest risk from a seismic activity because in its area the three geological elements happened to be in the same area and it has the epicenter has 5.3 earthquake magnitude that fairly high compared to other. The AHP method indicates that Tepebaşı has the highest with 26% and İnönü has only 7% risk percentage. The result from the two methods produces different district with a high risk that makes them not relevant to the study.

In Scenario 2 (Fault Line: 3, Lithology: 1, Epicenter: 2), the result in the GIS method shows that the district of İnönü has the highest seismic risk with 90% of Zone One area are located in the district. The AHP result showed Tepebaşı was the highest with 30% of the seismic risk. Since İnönü district has the highest risk in GIS and Tepebaşı in AHP it makes the two result again not relevant to the study.

In Scenario 3 (Fault Line: 3, Lithology: 2, Epicenter: 1), the GIS method and AHP method showed the same result of the district with highest seismic risk. In GIS method, Tepebaşı has the most extensive area of zone one that makes the area to be an extremely high risk. The district of İnönü shows not to be in the highest risk because when the Fault Line criterion is with the highest weight among all criteria and Epicenter turn to be the least, larger area in Tepebaşı turns into Zone One. And from AHP method, Tepebaşı is also consistent in highest risk with 25% of the risk.

The Fifth question that the study sought to answer is, "Based on GIS and AHP method, which among the three factors produced approximately the same results?"

GIS method showed a different result as to which district has the highest risk using the three different weight value of criteria (scenarios), unlike the AHP method, it showed a consistent result with high risk from seismicity which is the Tepebaşı district.

Among the three scenario's graph, the Scenario Three has relatively the same result from both methods compared to the results of Scenarios 1 and 2. The first and second scenario showed that İnönü District has the highest risk of GIS method and Tepebaşı in AHP method that makes the two methods not relevant.

The result of scenario three was not the same because of the different ways of the processes, but the result gave the closest result in both methods (Figure 21). From both graphs of scenario three, it showed higher similarity because the district with the highest risk was the same which was the district of Tepebaşı. The districts of Odunpazarı, Alpu, Günyüzü, and Han appeared to have the same risk value from both methods. Four out of fourteen districts have large different result values; these are the districts of İnönü with 15% difference, Sivrihisar with 6%, Sarıcakaya with 4%, and Mahmudiye with 4% difference. The rest of the districts have a very close result which shows the risk percentage has only around one to two percent differences. The close results of both methods became the deciding factors which consider the Scenario Three as the final result of the study and the weight importance to the three geological elements when comparing their influence when assessing earthquake risk.

7. CONCLUSIONS AND RECOMMENDATIONS

The study concluded that based on the analysis that the area exposed at the active fault line, soft ground (Alluvium), and experience earthquake with high magnitude (Epicenter) is highly prone to earthquake seismicity. It also concluded that Active Fault Line has the highest influence on earthquake due to its continuous movement that can cause energy generation beneath the ground (National Geographic Society, 2015). Next is lithology with soil characteristic like alluvium, S-wave can produce much higher disaster passing through soft grounds, and the Earthquake Epicenter because the repetition of the earthquake in the same area is possible; However it occur at intervals ranging from decades to several hundreds of years on average ("Understanding Earthquake", 2014).

Based on the finding generated from the study, the following recommendations are can be considerations;

When assessing seismic risk using the three geological elements as the criteria, the study recommends applying the weight value used in Scenario Three, which Fault Line grade 3, Lithology has grade 2, and Epicenter has grade 1.

The Provincial Government of Eskişehir can use the generated seismic risk map in their preparedness and mitigation program for the residence and essential industries.

The Provincial Health Ministry, based on the gathered data from Eskişehir Health Office, the number of doctors and nurses in the district of İnönü, Sarıcakaya, Mihalgazi, and Alpu should increase due to the degree of seismic risk in the area. Especially for Tepebaşı and Odunpazarı, although they have the highest risk from seismicity, the number of doctors and nurses are in good number. The health ministry may also use the map result to decide before building where to build any facility that will speed up the response when disaster comes.

Provincial Residence, for the safety of the residence, the seismic map produced in the study may serve as a guide map in selecting a residential area of preference.

This study shall also be conducted in other provinces of Turkey especially for those areas with history or vulnerabilities to earthquake incidence that is to assess the seismic risk using the same criteria and procedures.

Other researchers may conduct the same study with more precise and thorough process to confirm the integrity of the result using the same study area.

REFERENCES

AFAD, (1996). Earthquake Zoning Map of Turkey. T.C. Başbakanlik Afet ve Acil Durum Yönetimi Başkanliği Deprem Dairesi Başkanliğ (Republic of Turkey Ministry of Disaster & Emergency Management Authority),

Allen, C.R., (1982). Comparisons between the North Anatolian Fault of Turkey and the San Andreas Fault of California. Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125, USA

ArcGIS Server, (2016) WMTS services. Environmental Systems Research Institute, Inc.http://server.arcgis.com/en/server/latest/publish-services/linux /wmts-services.htm (Internet).

Armenakis, C., Xinheng Du, E., Natesan, S., Persad, R.A., and Zhang, Y., (2017). Flood Risk Assessment in Urban Areas Based on Spatial Analytics and Social Factors; Geosciences and Multidisciplinary Digital Publishing Institute (MDPI), No. 1-15.

Ashford SA, Jakrapyanun W, Lukkanaprasit P. (1997) Amplification of Earthquake Ground Motions in Bangkok. Final report on research sponsored by the Royal Thai Government, Public Works Department, Ministry of Interior, Thailand.

Assimaki, D., Kausel, E., & Gazetas, G. (2005). Wave propagation and soil–structure interaction on a cliff crest during the 1999 Athens Earthquake. Soil Dynamics and Earthquake Engineering, 25, 513-27.

Azarian, R., (2011), Potentials and Limitations of Comparative Method in Social Science. International Journal of Humanities and Social Science Vol. 1 No. 4.

Bayrak, Y., Çınar, H., and Bayrak, E., (2011). The North Anatolian Fault Zone: an Evaluation of Earthquake Hazard Parameters, New Frontiers in Tectonic Research - At the Midst of Plate Convergence, Dr. Uri Schattner (Ed.), ISBN: 978-953-307-594-5, InTech.

Bergman, J., (2016). What Is an Earthquake? Windows to the Universe, National Earth Science Teachers Association (NESTA). https://www.windows2universe.org/earth/geology/quake_1.html&edu=high.

Bolt, B.A., (2018). Earthquake; Encyclopædia Britannica, Encyclopædia Britannica, Inc., https://www.britannica.com/science/earthquake-geology

Borcherdt, R.D., (1994) Estimates of site dependent response spectra for design (methodology and justification), Earthquake Spectra, 10, 617–654.

Bouckovalas, G.D., & Papadimitriou A.G., (2005). Numerical evaluation of slope topography effects on seismic ground motion. Soil Dynamics and Earthquake Engineering, 25, 547-58.

Bradley, B.A., Cubrinovski M (2011) Near-source strong ground motions observed in the 22 February 2011 Christchurch earthquake. Seismol Res Lett 82(6):853–865

Bunruamkaew, K., (2012). How to do AHP analysis in Excel; Division of Spatial Information Science Graduate School of Life and Environmental Sciences University of Tsukuba. No. 1-21.

Daniell, J.E., Schaefer, A.M., and Wenzel, F., (2017). Losses Associated with Secondary Effects in Earthquakes. Frontiers in Built Environment, 2017; 3 DOI: 10.3389/fbuil.2017.00030

Duke, C. M. (1958) "Effects of Ground on Destructiveness of Large Earthquakes." Proc A.S.C.E., Vol 84, SM3.

Edwards, C., (2017). Seismic Shaking data for the Marin Countywide Plan Update; ArcGIS,https://www.arcgis.com/home/item.html?id=a076f9c3509d4262ae21c277d522221f

Erden, T. and Karaman, H., (2012). Analysis of earthquake parameters to generate hazard maps by integrating AHP and GIS for Küçükçekmece region. Nat. Hazards Earth Syst. Sci., 12, 475–483

ESRI, (2001). ArcGIS Spatial Analyst: Advanced GIS Spatial Analysis Using Raster and Vector Data; ESRI 380 New York St., Redlands, CA 92373-8100. No. 1-13.

ESRI, (2008). Cell Size of Raster Data; Environmental Systems Research Institute, Inc. (ESRI) http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Cell_size_of_raster_data

Esri, (2016). How Weighted Overlay Works; Environmental Systems Research Institute, Inc; http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm

ETO, General Structure of Eskişehir Economy, Eskişehir Ticaret Odasi (Eskişehir Chamber of Commerce). http://www.etonet.org.tr/etonet/

European Committee for Standardization – CEN, (2004). Eurocode 8: Design of structures for earthquake resistance – part5: Foundation retaining structures and geotechnical aspects, Comite European de Normalisation, 2, 48pp.

Farangitakis, G.P., Brentas, O.G., Andreadakis E., and Lekkas E., (2016). Seismic risk assessment in the Attica basin. Bulletin of the Geological Society of Greece, vol. L, p. 1415-1425. Proceedings of the 14th International Congress Thessaloniki.

Göncüoğlu, M.C., 2010. Introduction to the Geology of Turkey: Geodynamic evolution of the pre-Alpine and Alpine terranes. General Directorate of Mineral. Res. Explor., Monography Series, 5, 1-66.

IRIS and University of Portland, (2010). Buildings and earthquakes—which stands? Which falls? Teachable Moment resources for Haiti.

Jeffrey, J., (2005). Earthquake Natural or Man-made. Biblioteca Pleyades. http://www.bibliotecapleyades.net/ciencia/esp_ciencia_tsunami67.htm (Internet).

Kanaori, Y., (2000). Seismic risk assessment of an active fault system: The example of the Tsurugawan–Isewan tectonic line; Engineering Geology 56 (2000) 109–123.

Kanlı, A.I., Tildy, P., Pr´onay, Z., Pınar1, A., and Hermann, L., (2006). VS 30 mapping and soil classification for seismic site effect evaluation in Dinar region, SW Turkey.

Kaptan, K., (2015). Seismic risk assessment for rural areas. Küresel Mühendislik Çalışmaları Dergisi and The Journal of Global Engineering Studies Volume: 2 Issue:1

Klose, C., (2008). Sichuan Earthquake Damages Dams, May Be Dam-Induced. International Rivers, 2054 University Ave, Suite 300, Berkeley, CA 94704-2644, USA.

Kokusho, T. and Sato, K., (2008). Site amplification formula for seismic zonation based on downhole array records during strong earthquakes. The 14th World Conference on Earthquake Engineering, Beijing, China. No. 1-8.

Konstantinos, P., (n.d.) “The Analytic Hierarchy Process”. International Hellenic University. No. 1-5.

Kramer, S.L., (1996) Geotechnical earthquake engineering. Prentice Hall, New York

Lamont, (2017). The North Anatolian Fault; Doherty Earth Observatory, Columbia University | Earth Institute, http://www.ldeo.columbia.edu/tamam/tamam-background/the-north-anatolian-fault

Lepetu, J.P., (2012). The use of analytic hierarchy process (AHP) for stakeholder preference analysis: A case study from Kasane Forest Reserve, Botswana; Journal of Soil Science and Environmental Management Vol. 3(10), pp. 237-251

Lovett, R.A., (2011). Heavy Rainfall Can Cause Huge Earthquakes; National Geographic News.

Mann, S.H., (1995). Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges (1995). Inter’l Journal of Industrial Engineering: Applications and Practice, Vol. 2, No. 1, pp. 35-44.

Mekik, C., Kutoğlu, H., and Gormus, K.S., (2013). a; WIT Transactions on The Built Environment, Vol 132, WIT Press.

Milana, G.G., Azzara, R.M., Bertrand, E., Bordoni, P., Cara, F., Cogliano, R., Cultrera, G., Giulio, G.D., Duval, A.M., Fodarella, A. Marcucci, S., Pucillo, S., Régnier, J., Riccio, G., (2011). The contribution of seismic data in micro zonation studies for downtown L’Aquila , Springer Science+Business Media B.V. 2011. Bull Earthquake Eng (2011) 9:741–759

Miller, H.J., (2004). Tobler’s First Law and Spatial Analysis, Department of Geography, University of Utah, Blackwell Publishing, 350 Main Street, Malden, MA 02148, and 9600 Garsington Road, Oxford OX4 2DQ, U.K.

Nath, S.K., Adhikari, M.D., Devaraj, N., and Maiti, S.K., (2015). Seismic vulnerability and risk assessment of Kolkata City, India. Nat. Hazards Earth Syst. Sci., 15, 1103–1121

National Geographic Society, (2015). Plate Tectonics; https://www.national geographic.com/science/earth/the-dynamic-earth/plate-tectonics/

Nelson, S.A., (2013). Earthquake Hazards and Risks. Tulane University. http://www.tulane.edu/~sanelson/Natural_Disasters/eqhazards%26risks.htm

Nikjo, B., Rezaeian, J., and Javadian, N., (2015). Decision Making in Best Player Selection: An Integrated Approach with AHP and Extended TOPSIS Methods Based on Wefa Framework in MAGDM Problems; Int. J. Res. Ind. Eng. Vol. 4, No. 1-4.

OpenSHA and the University of Southern California, (2010). Shear Wave Velocity (Vs). Open Seismic Hazard Analysis (OpenSha) http://www.opensha.org/glossary-shearWaveVelocity.

Orhan, A., Seyrek, E., and Tosun, H., (2007). A probabilistic approach for earthquake hazard assessment of the Province of Eskişehir, Turkey; Nat. Hazards Earth Syst. Sci., No. 607-614.

Özsayin, E., and Dırık, K., (2007). Cihanbeyli ve Yeniceoba Fay Zonları'nın Kuvaterner Aktivitesi: İnönü-Eskişehir Fay Sistemi, Orta Anadolu; Turkish Journal of Earth Sciences. 2007, Vol. 16 Issue 4, p471-492. 22p

Öztel, D.Ç., Yaman, N., Sabah, L., Ayday, E., and Ayday, C., 2002. Önerici Sistemler ile Afet Bilgi Sistemi (Disaster Information System with Proactive Systems [Turkish]). Başarsoft Coğrafi Sistemleri Çozüm Merkezi and Coğrafi Veri Modelleme Sanayi ve Tecaret Limited Şerket.

Parton, I.M., and Melville Smith, R.W., (n.d.). Effect of soil properties on earthquake response. Auckland University School of Engineering and Civil Engineer, M.0.W. Structural Design Office, Auckland.

Pekkan, E., Tun, M., Guney, Y., and Mutlu, S., (2015). Integrated seismic risk analysis using simple weighting method: the case of residential Eskişehir, Turkey. Earth and Space Sciences Institute, Anadolu University, Eskişehir, Turkey

Phillips, A., (2017). Scales Used to Measure Earthquakes. https://sciencing.com/scales-used-measure-earthquakes-7238883.html

Rauch, A.F., (1997). EPOLLS: An Empirical Method for Predicting Surface Displacements Due to Liquefaction-Induce Lateral Spreading in Earthquake. Virginia Polytechnic Institute and State University.

Reed, S.B., (1992). Introduction to Hazards - 1st Edition (Department of Humanitarian Affairs/United Nations Disaster Relief Office - Disaster Management Training Programme - United Nations Development Programme, 168 p.

Rehman, S.U., Amir, N.A., Lindholm C., and Rafi, Z., (2012). Probabilistic Seismic Hazard Analysis for Quetta City, Pakistan. Pakistan Meteorological Department and NORSAR, Norway.

Saaty, T.L., 1980. Decision Making With the Analytic Hierarchy Process. Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, USA Int J Serv Sci 2008; 1:83

Sawada, Y., Bhattacharyay, R., and Kotera, T., (2011). Aggregate Impacts of Natural and Man-made Disasters: A quantitative comparison. RIETI, the Research Institute of Economy, Trade and Industry. http://www.rieti.go.jp/en/

Selçuk, A.S., Gökten Y.E., and Aktuğ, B., (2016). The Stress State of The Region around İnönü-Eskişehir active fault system (Turkey); kinematic analysis accompanied with GPS Data, J. Ind. Geophysics Union (November 2016) v.20, no.6, pp: 527-535

Semblat, J.F., Dangla, P., Kham, M., (2009). Laboratoire Central des Ponts et Chaussées, 58, bd Lefebvre, 75732 PARIS Cedex 15, France, semblat@lcpc.fr A.M. Duval, CETE Méditerranée, Seismic Risk Team, Nice, France

Shoji, Y., Tanii, K., and Kamiyama M., (2004). The duration and amplitude characteristics of earthquake ground motions with emphasis on local site effects; 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, Paper No. 436.

Sieh, K., 1996. The repetition of large-earthquake ruptures. Proc. Natl. Acad. Sci. USA. Vol. 93, pp. 3764-3771

Smart, C.L., (2016). PLATE TECTONICS, Introduction Continental Drift, Seafloor Spreading, Plate Tectonics, Divergent Plate Boundaries, Convergent Plate

Boundaries, Transform Plate Boundaries, Summary. KEAN University Union, NJ 07083.

Smolka A., and Berz, G., (1988). The Mexican Earthquake of September 1985 – Damage Statistic and Implications for Risk Assessment. Munich Reinsurance Company, KoeniginstraBe 107, D-8000 München 40.

Surve, R.B., and Kathane, B.Y., (2014). Disparity of Spatial and Non Spatial Data; International Journal of Advance Foundation and Research in Computer (IJAFRC) Volume 1, ISSN 2348 – 4853.

The Analytic Sciences Corporation–TASC, (1996). An Illustrated Guide to the Analytic Hierarchy Process. https://drive.google.com/file/d/1CwD3ZCpR98eL1VsaYvAhQrF4CYigeknu/view?usp=sharing

Tobler, W. R. 1970. A computer movie simulating urban growth in the Detroit region. Economic Geography 46:234–40.

TUİK, (2016). Turkiye Istatistik Kurumu - Turkish Statistical Institute; http://www.tuik.gov.tr/Start.do

Tyrologou, P., Parry, S., Hamor, T., Sanchez, N., Scharek, P.P., Bouvier, A., and Ganas A., (2015). Disaster Risk Reduction from natural hazards, The Role of Science; European Federation of Geologists, 13 Rue Jenner, B-1000 Brussels, No. 1-18

Understanding Earthquake. (2014, June 30). The Headquarters for Earthquake Research Promotion.

UPSeis, (2007). How Do I Locate That Earthquake's Epicenter? UPSeis an Education Site for Budding Seismologist. http://www.geo.mtu.edu/UPSeis/locating.html

UPSeis, (2007). Where Do Earthquakes Happen? UPSeis an Education Site for Budding Seismologist. http://www.geo.mtu.edu/UPSeis/where.html

Westaway, R., Demir, T., and Seyrek, A., (2008). Geometry of the Turkey-Arabia and Africa-Arabia plate boundaries in the latest Miocene to Mid-Pliocene: the role of the Malatya-Ovacık Fault Zone in eastern Turkey; Electronic Earth (eEarth), No. 27-35.

Http – 1. KOERI, (2017). Kandilli Rasathanesi ve Deprem Arastirma Entitüsü (Kandilli Observatory and Earthquake Research Institute). http://www.koeri.boun.edu.tr/sismo/2/earthquake-catalog/

Http – 2. PNSN, Richter Magnitude Scale and Mercalli Intensity Scale Modified Mercalli Intensity Scale. Pacific Northwest Seismic Network. https://pnsn.org/outreach/about-earthquakes/magnitude-intensity

Http – 3. MTA, (2017). Maden Tetkik Ve Arama Genel Müdürlüğü (General Directorate of Mineral Research and Exploration). http://www.mta.gov.tr/v3.0/

Http – 4. WMS data source:

http://yerbilimleri.mta.gov.tr:8080/geoserver/MTA/wms?version=1.1.0&layers=MTA:DIRIFAY&styles=&bbox=2875387.0,4291970.0,4980347.0,5141272.5&width=817&height=330&srs=EPSG:900913&