Investigation of local soil properties of Erzurum province (Eastern Türkiye) by Horizontal/Vertical Spectral ratio method

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ABSTRACT

Erzurum province is a basin developed under the effect of strike-slip faults in the Eastern Anatolia region. Erzurum province is generally influenced by the left strike-slip Erzurum Fault Zone, the left- strike-slip Aşkale fault, and the Başköy-Kandilli reverse fault. It is also located approximately 80 km from the Karlıova joint, which is the intersection of the North Anatolian and East Anatolian Faults. When the earthquakes of the instrumental and historical periods are analyzed, it is seen that many damaging earthquakes of medium to large magnitude have occurred in Erzurum province. Erzurum basin is generally covered with old alluvium at the edges of the plains, while the flat areas in the central parts are covered with new alluvium. Determination of local soil properties in regions with high earthquake hazard plays an important role in reducing earthquake risks. For this purpose, single station microtremor measurements were applied at 25 sites in Palandöken and Yakutiye districts of Erzurum province. The measurements were taken for at least 30 minutes and evaluated according to the Horizontal/Vertical Spectral Ratio method. As a result of the analysis, the dominant period, H/V ratio and vulnerability index (Kg) values of the measurement points were calculated. The period values obtained vary between 0.15 s and 3.7 s, while the H/V ratios vary between 2.2 and 8.5. The Kg value obtained using these parameters is defined as the vulnerability of the soil. It is concluded that high period, high H/V and high Kg values are obtained in areas with recent alluvium and multidisciplinary analyses should be performed in soil investigations in these regions.

Keywords: Erzurum, the Horizontal/Vertical Spectral Ratio, Dominant Period, Vulnerability Index.

1. Introduction

Erzurum province is located in eastern Turkey and is inhabited by approximately 800,000 people. The Erzurum basin is generally characterized as a pull-apart basin developed under the influence of strike-slip faults (Kocyigit and Canoglu, 2017). There are many active faults with different characteristics around Erzurum city center. It is also located approximately 70-80 km from the Karlıova triple joint, where the seismically very active North

Anatolian Fault and the East Anatolian Fault intersect. The Yedisu seismic gap, one of the important seismic gaps on the North Anatolian Fault, extends from Karlıova in the east to Erzincan-Tanyeri in the west (Zabci et al., 2017). Yedisu seismic gap will produce a magnitude 7.5 earthquake if it ruptures completely (Aktuğ et al., 2013). The instrumental and historical earthquake catalogs show that many destructive earthquakes have occurred in and around Erzurum province. According to the Turkish Building Earthquake Code (TBEC, 2018), the maximum expected acceleration values in Erzurum province for a return period of 475 years vary between 0.4g and 0.5g. The effect of local soil properties on the expected acceleration values is a known fact. It is known that the amplitudes of earthquake waves increase in loose soils compared to firm soils and soil amplification occurs (Kramer, 1996).

Determination of local soil properties is one of the important steps in risk mitigation studies, especially in Erzurum province, which is under high earthquake hazard. Local soil properties can be determined by geophysical and geotechnical studies. Although the most commonly used geophysical methods are Multi-Channel Surface Wave Analysis Method (MASW), Seismic Refraction and Refraction Microtremor (ReMi), in recent years, soil properties can also be determined quickly and practically with the single station microtremor method. The advantage of the single station microtremor method over other methods is that it does not require much equipment in the field and fast measurements can be taken. Soil dominant frequency and amplification factor parameters can be determined from microtremor data by the H/V method described by Nakamura (1989, 2000). There are many studies conducted with the H/V spectral ratio method to determine soil properties in the world (Nakamura 1989; Lermo and Chávez-García 1993; Field and Jacob 1995; Konno and Ohmachi 1998; SESAME 2004) and in Türkiye (Akin and Sayil 2016; Pamuk et al., 2017, 2018; Pamuk 2019; Akkaya 2020; Pamuk and Ozer, 2020; Akbayram et al. 2022; Karsli and Bayrak, 2024; Coban, 2024). Keskin et al. (1998), Koçyiğit and Canoğlu (2017) studied the tectonic and geological evolution of Erzurum. Geothermal properties were studied by Bektaş et al. (2007), Özer and Özyazıcıoğlu (2019). Local soil properties were discussed by Özer (2019), Karsli and Bayrak (2024). Earthquake hazard around Erzurum were investigated Bayrak et al. (2020), Coban and Sayil (2020), Celebi et al. (2023), Özyazıcıoğlu et al. (2024).

The main objective of this study is to obtain the variation of soil dominant period and amplification factor values in Erzurum city center. For this purpose, single station microtremor measurements were taken in 25 different areas. This study contributed to the determination of the soil properties of Erzurum city center on a large scale and to fill this gap in the literature.

2. Geology and Tectonics

After the uplift of volcanic materials in Erzurum and its vicinity, it took its present shape by filling the plains with the flow of alluvial materials flowing from the Karasu and Palandöken mountains (Koçyiğit and Canoğlu, 2017). Three different formations are commonly observed in the study area. These are Upper Miocene-Pliocene Çobandede (Erzurum) volcanite, older Quaternary alluvium and more recent alluvium (Akbaş et al., 2011). Erzurum Fault Zone, Kandilli Fault, Palandöken Fault, Pasinler Fault Zone and Horasan-Şenkaya Fault Zone are the first order faults that can affect Erzurum. Erzurum Fault Zone has sub-segments, some of which pass directly through the settlements of the city (Figure 1). During the instrumental period, destructive earthquakes occurred on the Pasinler Fault Zone in 1924 and on the Horasan-Şenkaya Fault Zone in 1983. According to past studies on the Erzurum Fault Zone, it has been emphasized that this fault has the potential to produce earthquakes of approximately 7.1 magnitude (Emre et al., 2004; Kocyigit and Canoglu, 2017; Emre et al., 2018).

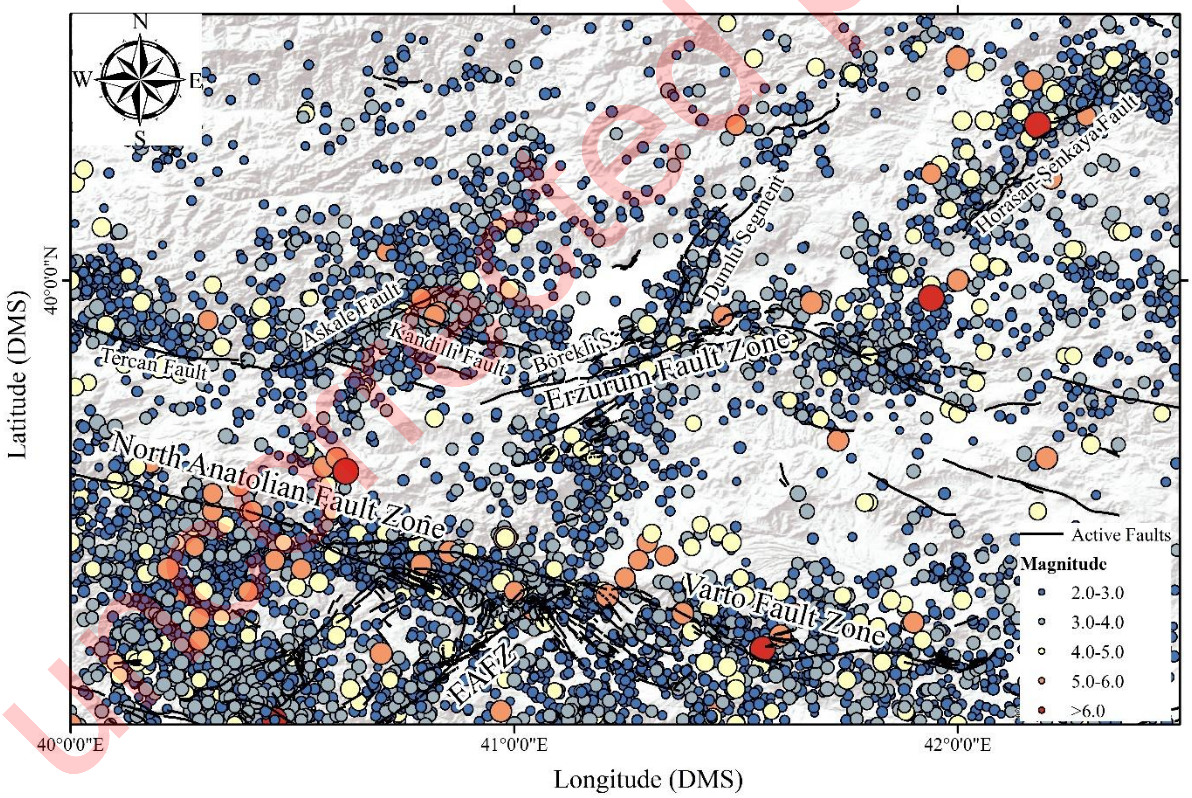

Figure 1- Active faults in Erzurum and its vicinity and epicentre distribution of earthquakes occurring between 1900-2024 (Active faults are digitized from Emre et al., (2013). Earthquake data were obtained from KOERI (2024). EAFZ: East Anatolian Fault Zone, Börekli S: Börekli Segment).

3. Data and Method

3.1. Single Station Microtremor Data

Single station microtremor data were collected at 25 different locations to investigate the soil properties of Erzurum city centre (Figure 2). In the selection of measurement points, the areas where drilling and MASW studies were previously carried out preferred. Time periods with low ambient noise were selected for data collection. Measurements were taken using a 3-component seismometer. Data were collected for at least 30 minutes when the noise was low, while this time was increased when the noise was high.

The data obtained were evaluated in GEOPSY (Wathelet et al., 2020) considering SESAME (2004) criteria and soil properties (period, H/V) were determined (Figure 3). In this study, bandpass filtering (0.05 - 20 Hz) and cosine smoothing with 5% operator were performed in the data processing stages while evaluating the data with microtremor method. Windows of at least 25 seconds were used. In the calculated spectra, the b coefficient was set to 40 and Konno-Ohmachi rounding was applied (Konno and Ohmachi, 1998).

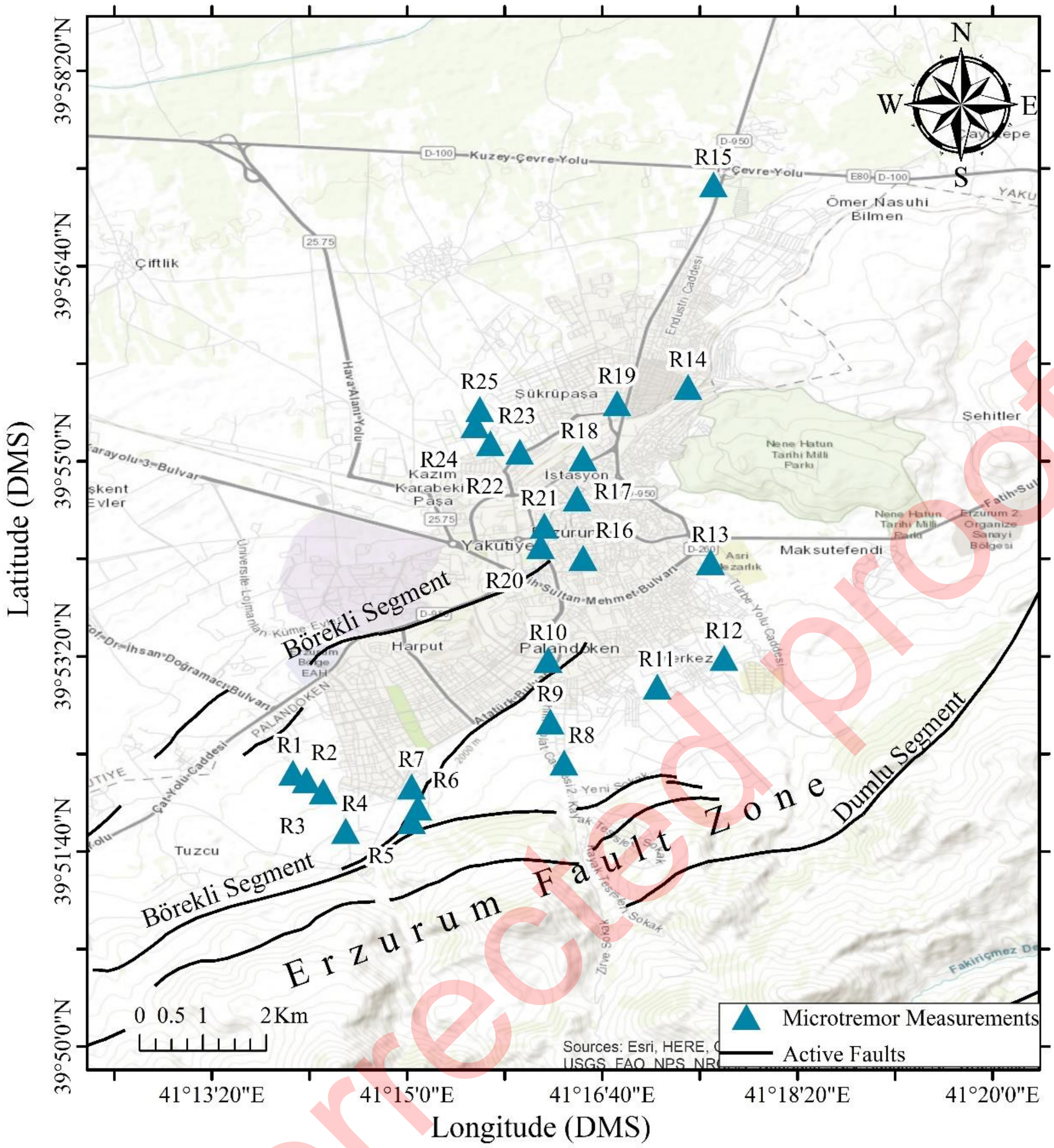

Figure 2- Distribution map of single station microtremor measurement sites (Active faults were obtained Emre et al., 2013).

3.2. Nakamura (H/V) Method

The Horizontal Component to Vertical Component Spectral Ratio (Nakamura's method, HVSR) method has shown that regional soil effects at a single location. This technique is widely used to obtain the effects of soil conditions. With this method, the dominant period of ground motion, which depends on local soil conditions, can be determined. This method hypothesises that microtremors are generated by vibrations from sources close to the surface (Nakamura 1989, 2000, 2019). HVSR is calculated by equation 1 (Nakamura, 1989);

$$HVSR = \sqrt{(NS^2) + (EW^2)} \Big/ Z \quad (1)$$

In the equation, NS and EW are the amplitude spectra of the North-South and East-West components respectively and Z is the amplitude spectrum of the vertical component.

The HVSR curve is first obtained by microtremor method and the largest value of the curve is determined as the amplification factor and the frequency value corresponding to this value is determined as the soil dominant frequency (Figure 3). Then, by using these parameters, parameters such as vulnerability index and elastoplastic properties of soils can be obtained by using empirical relations (Nakamura, 1997; Ibs-Von Seht and Wohlenberg 1999; Nakamura, 2000; Nakamura, 2019; Aydın et al., 2022).

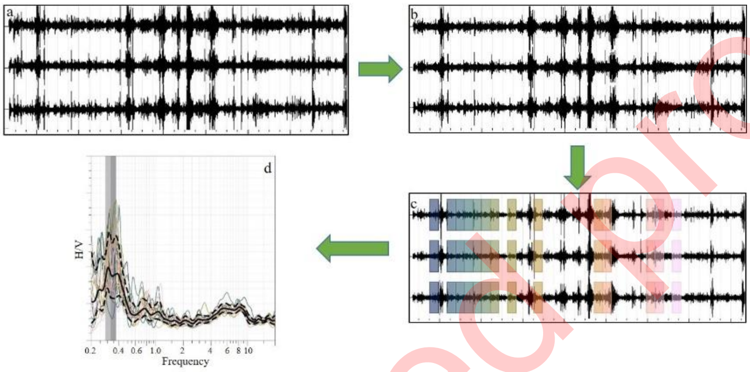

Figure 3- Schematic illustration of Nakamura H/V method a) Raw data, b) band-pass filtered data in the range 0.05-20 Hz, c) choosing the appropriate time windows, d) H/V curve to determine the dominant frequency and amplification factor.

3.2.1. Vulnerability Index (Kg)

Nakamura (1997, 2000) evaluated the correlation between the vulnerability index (Kg) and the amplification factor (A) and period (T) in his studies. The hazardous areas in the study area can be identified by this method before the earthquake occurs and calculated the value of the vulnerability index (Kg) as follows:

$$(Kg) = A^2 * T \tag{2}$$

Where, A and T are amplification factor and period values respectively.

4. Discussion

Microtremor data collected at 25 different points in the study area were evaluated using Geopsy (Wathelet et al., 2020) software. Soil dominant period (1/frequency) and amplification factor (H/V) values were calculated by H/V technique. In the study area, period values vary between 0.4 and 3.0 sec (Figure 4). Small period values were obtained in the south-southwest of the study area. This area is located on the foothills of Palandöken Mountain and therefore it is thought that the alluvial thickness is not very high. However, relatively high period values were observed at the R2 and R7 measurement points. It is observed that the period values increase significantly towards the north of the study area, i.e. towards the middle of the plain. It is important to pay attention to the resonance effect in the constructions in the area where high period values are observed (in the area of R16-R25 measurements) and to carry out the soil investigations with a multidisciplinary approach. In the area where R1-R7 measurements are located, period values are highly variable and it is important to perform soil investigations on a parcel-specific basis for safe building design.

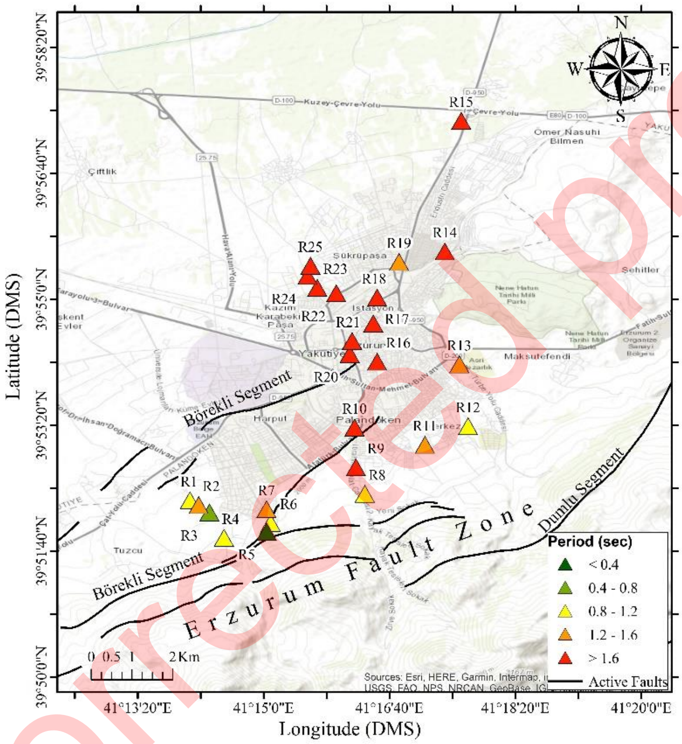

Figure 4- The soil dominant period (T) map (Triangles show measurements sites, black lines represent active faults, active faults were obtained Emre et al., 2013).

The amplification factor values are an indication of how much the amplitudes of the earthquake waves are increased. The amplification factor values derived by the H/V method vary between approximately 2 and 9 (Figure 5). Low HV values (<4) were obtained in the southern part of the study area where Palandöken Mountain is located. Larger HV values were obtained in the north of the study area. This region coincides with the starting area of the plain and it is thought that high HV values were obtained for this reason. High HV values were obtained in the area where high period values were observed.

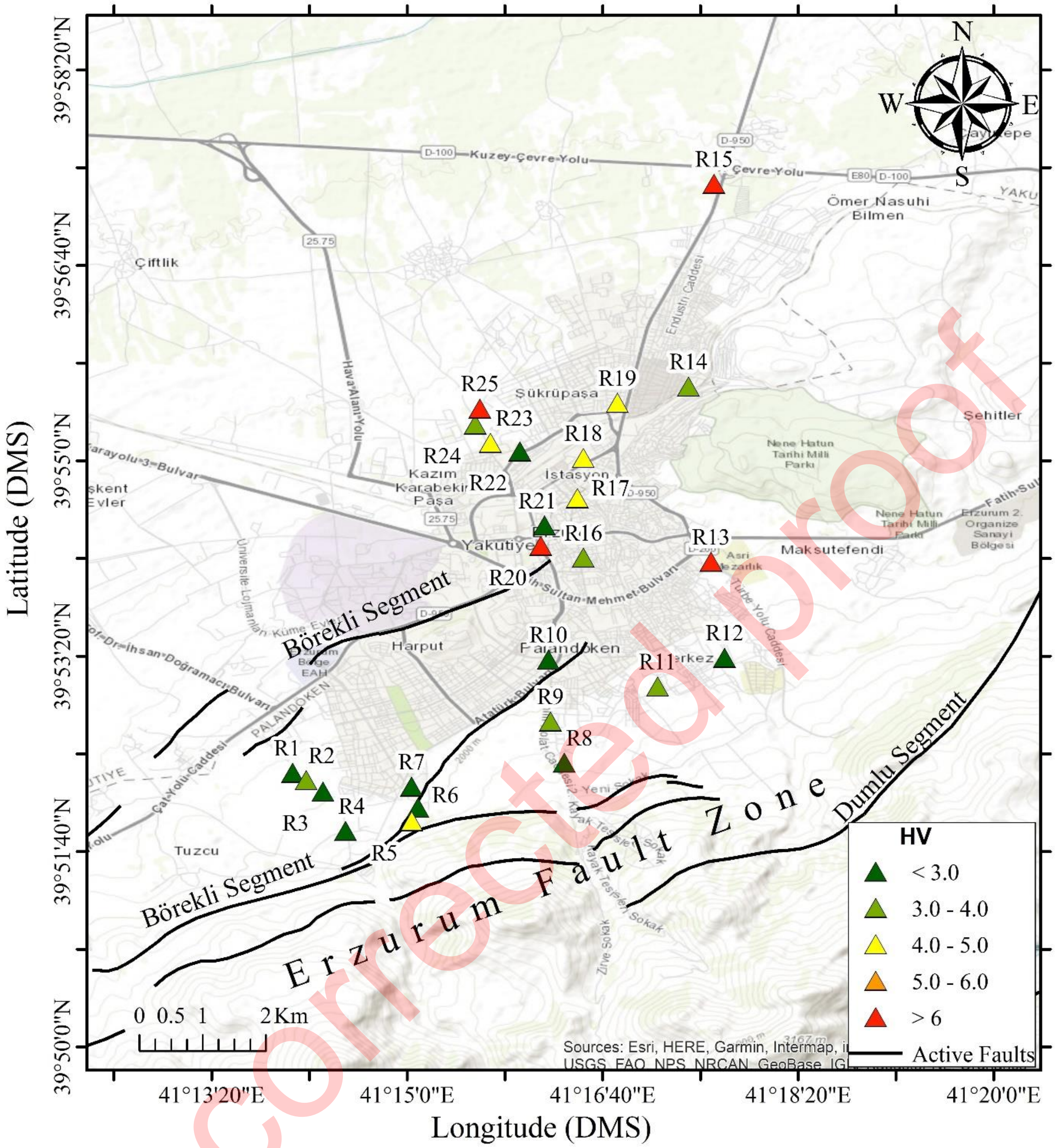

Figure 5- The amplification factor (HV) map (Triangles show measurements sites, black lines represent active faults. Active faults were obtained Emre et al., 2013).

Kg value is a very important parameter that gives information about the behavior of soils during earthquakes. This parameter is associated with amplification factor and period value (Nakamura, 1997). The Kg value was obtained with the help of the amplification factor and period value obtained by Nakamura method. Figure 6 was created to examine the spatial variation of Kg value in the study area. Kg values lower than 10 were obtained in the south of the study area. The relationship between Kg and the damage caused by the 7.2 magnitude earthquake that occurred in Van in 2011 was examined by Akkaya (2020). It was revealed that areas with a Kg value greater than 10 overlap with areas where damage is intensified. Kg value was especially high in the north of the study area. Soil properties should be considered in detail for the construction in this area.

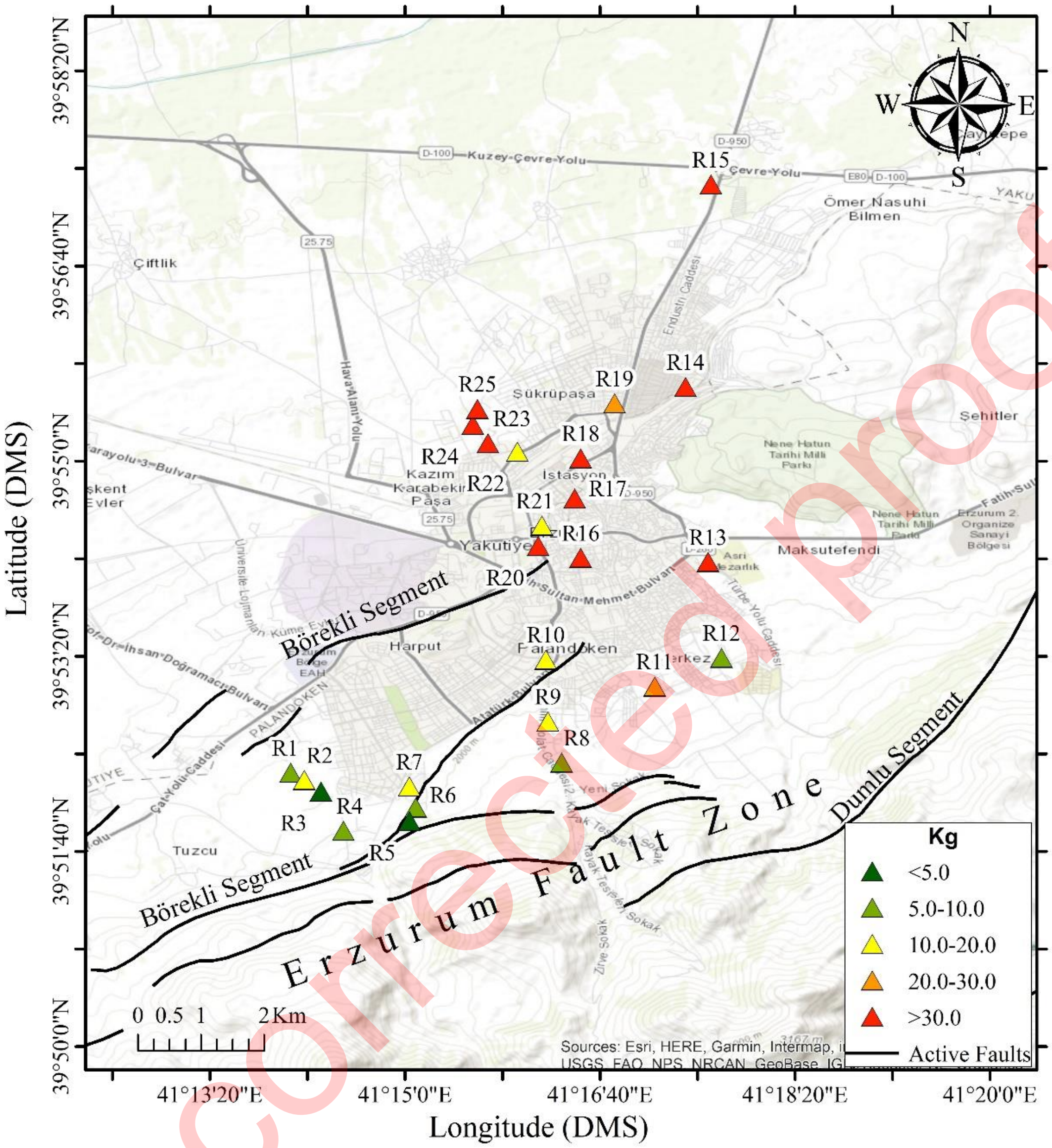

Figure 6- The vulnerability index (Kg) map (Triangles show measurements sites, black lines represent active faults. Active faults were obtained Emre et al., 2013).

5. Results

In this study, the soil dominant period and the amplification factor values, which are local soil properties, were determined for Erzurum province. The dominant period and amplification factor (H/V) parameters were obtained after the evaluation of the microtremor data with the Nakamura method. There is an inverse relationship between the period value and the soil strength. In other words, as the period value increases the soil strength reduces. Period values were found to vary between 0.4 and 3.0 s. Low period values were obtained in the south while high period values were obtained in the north. High period values were obtained in the lowland region. At the foothills of Palandöken Mountain, low period values were observed. According to these period values, it can be said that the ground gets poorer as one descends from the foot of the mountain to the plain. The amplification factor is also a useful parameter calculated by Nakamura's method. Amplification factor value has a range between 2 and 9. Amplification factor value has a range between 2 and 9. HV values less than 4 were observed in the foothills of Palandöken Mountain in the south of the study area. Larger values were obtained in the plain. It can be concluded that the high alluvial thickness in the plain is associated with a high amplification factor. The vulnerability index (Kg) obtained by using the period and amplification factor values provides information about the soil behavior during earthquakes. High Kg values were obtained especially in the north of the study area. When all these parameters are analysed together, it is seen that high period, high HV and high Kg values are concentrated in the north of the study area. Soil investigations in this area should be carried out very carefully and with a multidisciplinary approach.

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