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RESEARCH ARTICLE / ARAŞTIRMA MAKALESI

DEUNET (Dokuz Eylul University Seismological Observation Network): Seismicity of Izmir and Its Surroundings with A New Local Seismic Network in Western Anatolia

DEUNET (Dokuz Eylül Üniversitesi Sismolojik Gözlem Ağı): Batı Anadolu'da Yeni Bir Yerel Sismik Ağ ile İzmir ve Çevresinin Depremselliği

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Abstract

Local and regional networks are needed to better examine the regions with complex tectonism, such as western Anatolia. Local seismic networks may provide critical data to both scientists and local authorities. They are also required as a base for future early warning systems which Izmir, the largest city in the western Anatolia, does not have one. With the support of Dokuz Eylul University, Engineering Faculty and the Department of Geophysical Engineering the installation of a new local network DEUNET established on February 15, 2019, to obtain new and detailed information about Izmir and its surroundings by observing microearthquake activity as well as major and damaging earthquakes in the region. The obtained maps indicate that the network in this period has the capability to detect and locate local, regional and teleseismic earthquakes occurred. According to the results, an intense seismic activity was observed in the northeast and southwest of the station network from its establishment to the present. These recent active areas affected by two large earthquakes which one is called Aegean Sea – Samos earthquake and the other is Manisa earthquake occurred and affected Izmir City and its surroundings. We also examined the focal mechanism solutions of some recorded earthquakes in this paper. In addition, the ground characteristics of the station locations were examined using the recorded earthquakes. Since Dokuz Eylul University is the only university in Western Anatolia that offers seismology education, this network will also provide significant benefits for seismology education.

Keywords: *DEUNET, seismic network, earthquake, seismotectonic, seismic activity*

Öz

Yerel ve bölgesel sismik ağlar, Batı Anadolu gibi karmaşık tektonizmaya sahip bölgeleri daha iyi incelemek için gereklidir. Yerel sismik ağlar, hem bilim insanlarına hem de ilgili makamlara kritik veriler sağlamaktadır. Ayrıca, Batı Anadolu'nun en büyük şehri olan İzmir'de olması gereken erken uyarı sistemleri için bir temel olarak da değerlendirilmektedir. 15 Şubat 2019'da yeni bir yerel ağ olan DEUNET, Dokuz Eylül Üniversitesi Mühendislik Fakültesi ve Jeofizik Mühendisliği Bölümü'nde, büyük depremlerin yanı sıra mikro deprem aktivitelerini de gözlemlemek, İzmir ve çevresi hakkında yeni ve ayrıntılı bilgiler elde etmek için kuruldu. DEUNET deprem gözlem ağından elde edilen sonuçlar, bu dönemde meydana gelen yerel, bölgesel ve telesismik depremleri tespit etme ve konumlandırma yeteneğine sahip olduğunu göstermektedir. Yapılan değerlendirmelere göre DEUNET istasyon ağının kurulumundan günümüze, İzmir İl'inin özellikle kuzeydoğu ve güneybatısında yoğun bir sismik aktivite gözlenmiştir. Gözlemlediğimiz yoğun sismik aktivitenin nedeni de; Ege Denizi-Sisam ve Manisa depremlerinden dolayı meydana gelen yoğun artçı aktivitesidir. Bu depremler İzmir İl'i ve çevresini etkilemiştir. Bu çalışma kapsamında istasyon ağı tarafından kaydedilen depremlerin odak mekanizması çözümleri de incelenmiştir. Ayrıca kaydedilen depremler kullanılarak istasyon lokasyonlarının zemin özellikleri araştırılmıştır. Batı Anadolu bölgesinde sismoloji eğitimi veren tek üniversite Dokuz Eylül Üniversitesi olduğundan, bu ağın sismoloji eğitiminde de önemli katkıları olmaktadır.

Anahtar Kelimeler: *DEUNET, sismik ağ, deprem, sismotektonik, sismik aktivite*

1. Introduction

The neotectonism of the western Anatolia is generally explained by the movement of the Anatolian block to the west with respect to the Eurasian plate, and counterclockwise rotation along the Aegean Sea while overlapping it on the Aegean Arc in the southwest direction (Figure 1). The Aegean region has been under a N-S extensional regime since the Miocene while it has moved westward at a velocity of 2 cm per year due to the convergence of the African and Eurasian plates. Izmir located in the western part of Anatolia contains basin and corresponds approximately to the zone limited by grabens. Due to these movements of Western Anatolia, large and microearthquakes have occurred in Izmir and its surroundings throughout historical and modern time. [1-5]. Many researchers also investigated the seismic activity, tectonism and stress field

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around the Aegean Sea and Western Anatolia [6-15]. In Western Anatolia, grabens extending in the E-W direction are limited by normal faults, and the current deformation and related seismicity in the region are controlled by active faults. The magnitudes of earthquakes clustering type in time and space are small and medium [16]. Focal mechanism solutions are also compatible with important geological structures [17-18].

Over a period of about 27 years (Figure 1), the earthquakes in Izmir and its surroundings mostly occur around gulf of Izmir, Aegean Sea, northwest of Izmir and grabens.

Based on the need to observe the microearthquakes occurring in Izmir and its surroundings, the faults threatening the city and to detect the events of the Aegean Sea, the establishment of a local station network was planned in the region. After the installation of the five stations, several large earthquakes, such as 22.01.2020 Manisa-Akhisar earthquake Mw5.4, 26.06.2020 Manisa-Saruhanlı earthquake Mw5.5 and 30.10.2020 Aegean Sea-Samos earthquake Mw6.9 [20] occurred. Izmir was affected by these earthquakes, and particularly Aegean Sea - Samos earthquake brought about fear and panics, as well as caused damage in some districts of Izmir. These events also proved that it was important to monitor seismicity in the region. Therefore, we installed a permanent five-station real-time broadband seismic network named DEUNET (The Dokuz Eylul University Seismological Observation Network) on February 15, 2019. The aims of the network can be categorized as scientific and educational. On the one hand, the data generated by this network will be used to better identify the seismogenic areas within the region and characterize the seismic sources originated in this area, as well as to study the propagation of seismic waves in Izmir. From the educational point of view, training students by using real earthquake data will be an essential purpose of DEUNET.

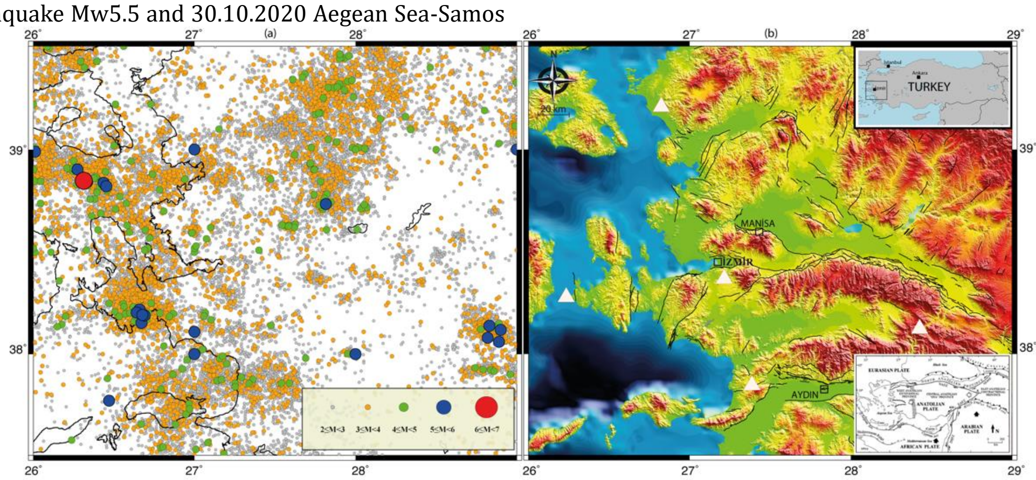

Figure 1. Recorded seismicity and topographic map of the investigated area (a) earthquake epicenters proportionally between 1992 and early 2019 from AFAD database. (b) locations of the DEUNET stations. Faults are simplified from tectonic map of MTA [19]. The top right corner and the bottom right corner of the inset maps show the study area in Turkey and tectonism of the Anatolian Plate [21], respectively.

2. Material and Method

Installation and maintenance of seismic networks are costly. For this reason, we wanted to provide a seismic network to our university by repairing some idle seismometers previously used in portable studies. Instrumentation consists basically CMG-6TD Guralp 30s seismometers. Digitation is obtained through a 24-bit A/D converter, which gives an effective dynamic range of 130 dB for Guralp. In the case of stations equipped with Guralp sensors, their output voltage is proportional to the ground velocity, with flat response between 0.0167 and 50 Hz. To obtain these responses, the signals are sampled continuously at 0.01 Hz, with continuous recording at 100 Hz. The instruments are protected from the environment through a cabin and wire mash (Figure 2). The sensors are placed on a concrete block, isolated from the environment, and built on bedrock.

To place the stations on a solid ground was our priority. We also considered it best to confine the network within the boundaries of Izmir so that we can observe the earthquakes occurring at the Aegean Sea (Table 1). Considering that the city is under high seismic risk, the locations of the stations were chosen to cover a large part of Izmir Metropolitan.

Figure 2. Instruments of the DEUNET seismic network (station installation).

Associated with the sensors, there is an electronic set composed of solar energy control module with solar panels, battery chargers, port server for modem communication and GPS antennas, digitizer CMG-EAM and protectors for both high voltage and lightning. Data are sent with internet (3G/4G) in real time by router to server and workstation in Seismology Laboratory of the Department of Geophysical Engineering (Figure 3). Phase picking, computing magnitude and the location of the earthquakes were managed by careful inspection with SEISAN software [22].

The DEUNET database includes continuous data with the raw data of gcf format and archived by a server during real-time data acquisition. We also use SAC, ASCII formats to analyze the data for different studies. The continuous data are also displayed on the web page of our department as drumplots (http://jeofizik.deu.edu.tr/en/deunet/).

Table 1. Geographic coordinates and elevations of the DEUNET stations and the sensor type.

Code	Province	Elevation (m)	Latitude (°N)	Longitude (°E)	Sensor Type
DCES	Cesme	40.1	38.279266	26.233676	30s-100Hz
DDKL	Dikili	122.6	39.206848	26.823387	30s-100Hz
DEUN	Buca	236.3	38.369015	27.214154	30s-100Hz
DKRZ	Kiraz	782.4	38.124343	28.426597	30s-100Hz
DSLC	Selcuk	204.5	37.845751	27.386309	30s-100Hz

Automatic processing is in the stage of the integration with SEISCOMP 4 to analysis our real time data and alert phase of the DEUNET network (Figure 3,[23]).

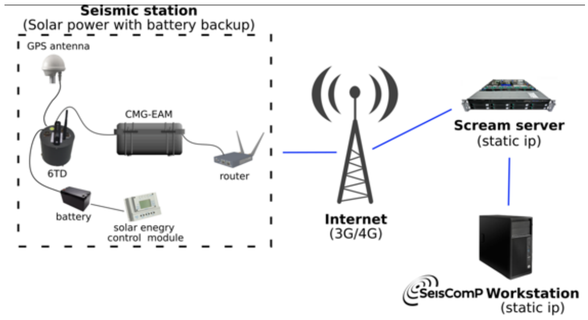

Figure 3. Schematic view of data flow of the DEUNET and real time data acquisition from five stations to the Seismological Laboratory of the Department of Geophysical Engineering

The quality of data is the main concern. In general, the records from at least five stations are used to provide an accurate location of an earthquake. When this requirement is not met, the errors will be numerous. For this reason, we make calculations based on at least five stations to minimize RMS. The data is exchanged with national seismic network AFAD [20] via a protocol. We are also willing to work with international seismic networks.

The network's detection capability of local and teleseismic events is illustrated in Figure 4. The first event is the north Karaburun earthquake with a local magnitude of M_L3.6, and the second one is the Jamaica earthquake which is a teleseismic earthquake with magnitude M_W7.7 occurred in NNW of Lucea, Jamaica.

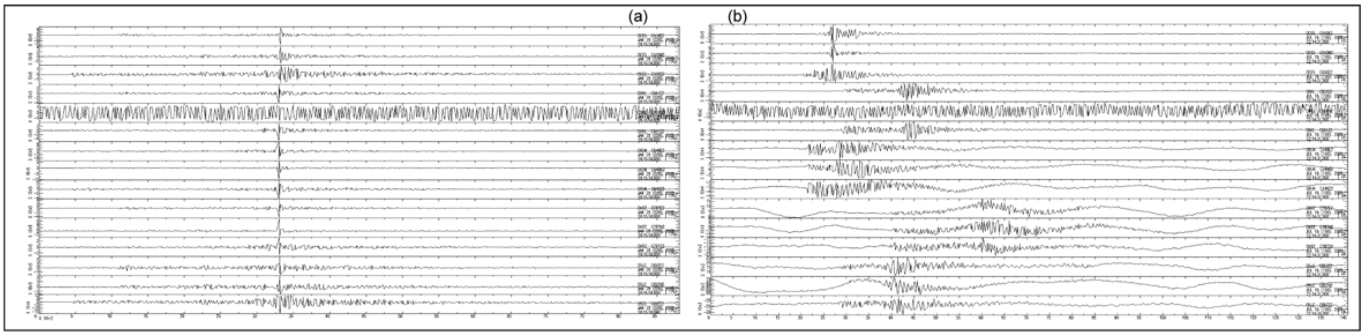

Figure 4. (a) 19.05.2019 M_L3.6 North Karaburun (South of Lesbos Island) earthquake (b) 28.01.2020, M_w7.7 teleseismic earthquake NNW of Lucea, Jamaica

In this study, we investigated site properties of station locations using local earthquakes recorded by DEUNET to ensure the location of the stations and reveal the quality of data. We analyzed site transfer functions of the stations using the horizontal-to-vertical spectral ratio (H/V) method. We selected the S-wave phase from three-component earthquake records with the appropriate azimuthal distribution, and then computed the Fourier amplitude spectra. The magnitudes (M_L) and epicenter distances of 53 earthquakes recorded in the network vary between 4.0 and 5.3, and 20 and 300 km, respectively. We observed different amplifications according to the site characteristics and illustrated these amplifications for different selected frequencies. Site function estimates reveal that there are significant amplifications in specific frequency ranges at some investigated sites.

3. Results

Since the installation of the DEUNET, many earthquakes have been recorded. The whole dataset is composed of 1136 events with the magnitudes ranging from 0.9 to 7.7 for local and distant earthquakes. Without the DEUNET it would not be possible to record the local seismicity of low magnitude ($0.9 \leq M < 3$) in the Izmir Metropolitan area. As a result of the restriction of at least five station readings, the locations of 665 earthquakes recorded were characterized by an RMS of less than 0.2 s (Figure 5).

We have added the five AFAD stations to our local network to improve our solutions from February 2021 as seen on the Figure 5 with gray triangles. Seismicity recorded by DEUNET has illuminated major seismic areas inside the study area. These major seismic areas are Manisa and Aegean Sea – Samos earthquakes and their aftershocks. These two earthquakes strongly dominate the seismicity shown in this figure. After a five-month earthquake sequence in Manisa, an earthquake occurred in the north of the island of Samos which is devastating for Izmir. On October 30, 2020 at 11:51 UTC, a Mw 6.9 earthquake struck Izmir, starting a sequence that is still ongoing while we are preparing this paper.

Figure 6 shows the record of this earthquake, with the epicenter off the coast of Kusadasi. It was also recorded by several national stations including AFAD (Republic of Turkey Ministry of Interior Affairs Disaster and Emergency Management) and KOERI (Kandilli Observatory and Earthquake Research Institute) (http://www.koeri.boun.edu.tr/scripts/lst8.asp). Our network has been clipped because we are very close to the earthquake, we only have the image of it as drumplots (Figure 6).

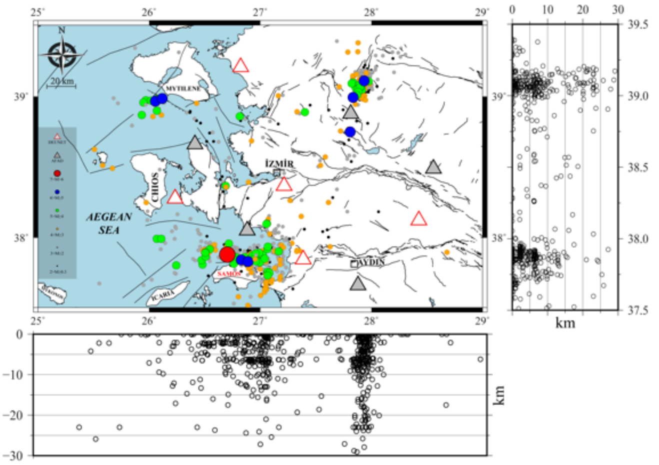

Figure 5. Seismicity recorded by DEUNET along the period of February 2019– August 2022 with longitude and latitude depth sections.

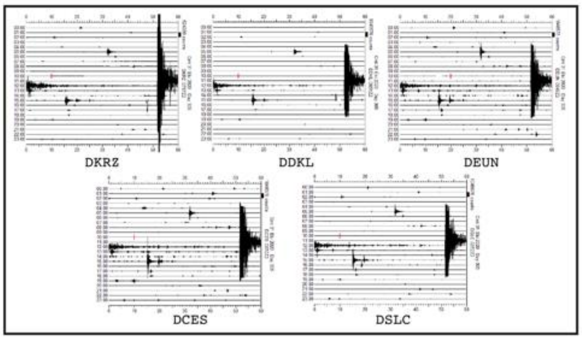

Figure 6. DEUNET drumplots of the 30 October 2020 11:51 UTC Aegean Sea - Samos earthquake

The Aegean Sea-Samos earthquake is thought to be caused by 30 km rupture on the Samos Fault. 117 citizens lost their lives and, 1032 were injured in a densely populated neighborhood in Bayraklı district due to the damage and the collapsing of the buildings by earthquake-related ground motions. The most remarkable features of this earthquake are the destruction it has caused at a location approximately 70 km far away from the earthquake epicenter, and the damages by the earthquake-induced tsunami waves along the shoreline of Seferihisar district, as reported by national agencies [20].

5099 aftershocks over a period of 41 days after the earthquake were reported by national institutes. The aftershock distributions indicate that there are some diffused seismic activities in the region (Figure 5). The focal depths of the aftershocks are observed down to about 15 km. This distribution of the aftershocks implies that the source was an E-W trending normal fault. At the easternmost of the island with a normal fault, depth of the events reach about 15 km. Earthquake distributions were also present on the right-lateral fault, but the large amount of the aftershocks occurred at the west of the Samos Fault.

There are also some diffused seismic activity inner and outer Bay of Izmir, north of the Karaburun Peninsula and Cesme area. We also observed some activity north of the study area and around Izmir City center. The seismic activity of the southwest of the Mytilene Island is also possible the ongoing movement of the aftershocks of M_w6.2 Mytilene earthquake that occurred on June 12, 2017.

Based on the latitude and longitude depth sections, it is possible to limit the depths of the earthquakes occurring in the region to the first 30 km of the earth's crust. The events concentrated in the south of the Izmir and north-east of the study area have focal depth estimations less than 10 km. Two clusters are observed at the depth sections: (1) NE of the Izmir City; this activity is related with the Manisa earthquakes, and its aftershocks are concentrated with point-source model at depths mostly to 10 km and (2) activity of south of Izmir, that is north of the Samos Island; related with the Aegean Sea – Samos earthquake. The hypocenters of this cluster are diffused compared to the seismic activity of Manisa could be related to the Samos Fault.

To examine the seismic movements affecting the study area in more detail, the focal mechanism solutions of earthquakes with a GAP < 200^{o} were calculated. The seismotectonic of the region were investigated by including AFAD stations to our solutions, using the FOCMEC algorithm [24] with polarity and amplitude ratios. We used the FOCMEC to find best-fit focal mechanisms, with calculated the double couple earthquake focal mechanisms using polarities and amplitude ratios. With this method, we tried to overcome the multi-solution problem caused by our small number of stations.

We determined that most of the seismicity in the region tends to concentrate near the normal faults. In addition to normal faulting systems, we detected strike-slip faults and small amount of reverse-slip fault mechanism. In Figure 7, the red line shows the focal mechanism of the Samos earthquake, the other two gray line next to red line are the focal mechanisms of the two large aftershocks that occurred after the main shock that three solutions of them are taken from the AFAD. Focal mechanism solutions of other earthquakes that occurred in the north and east of Samos Island. The other aftershocks located to the east of the main shock have analyzed with DEUNET stations that normal and reverse fault mechanisms with strike-slip component are observed in and around Kusadasi Bay.

Results of 30 October 2020 11:51 UTC Aegean Sea - Samos earthquake (Mw6.9) and its aftershocks from analysis DEUNET stations. The focal mechanism solutions of the mainshock and two biggest aftershocks illustrated from report of AFAD 2020. Faults lines are shown from GEM fault database [28]. Red line triangles show DEUNET stations, while gray triangles show AFAD stations.

Earthquakes that are located in the south of the Mytilene Island were also evaluated and focal mechanism solutions indicated in Figure 7. These earthquakes with different mechanisms were detected because of the earthquake activity that occurred on February 1, 2021, in the nearby location of the Mytilene earthquake with a magnitude of M_w6.2 in 2017. While three of these are normal faults with strike-slip component, two of them are reverse faults with strike-slip component.

The site characterization estimations made using 53 earthquakes selected in DEUNET database reveal that there are significant amplifications in certain frequency ranges in the DCES station. In general, although there are slight differences between the results of the shapes of the transfer functions in all cases. An increase in amplitude was observed at high frequencies the DEUN station. In this study, amplitude increases were not observed in the other stations (DKRZ, DSLC and DDKL). However, after that first peak, the amplitude of the noise HVSR decreases and no information is retrieved for amplification observed at higher frequencies in the earthquake data (Figure 8). This problem had been already signaled in [29].

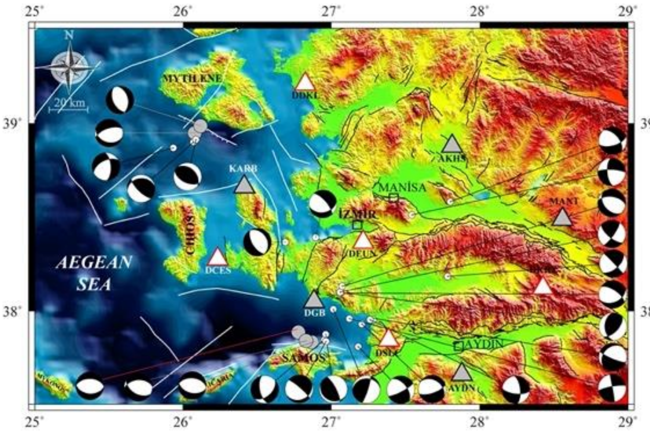

Figure 7. Representation of the focal mechanism solutions of 26 earthquakes with magnitudes ranging from 2.3≥M≥7 [25-27].

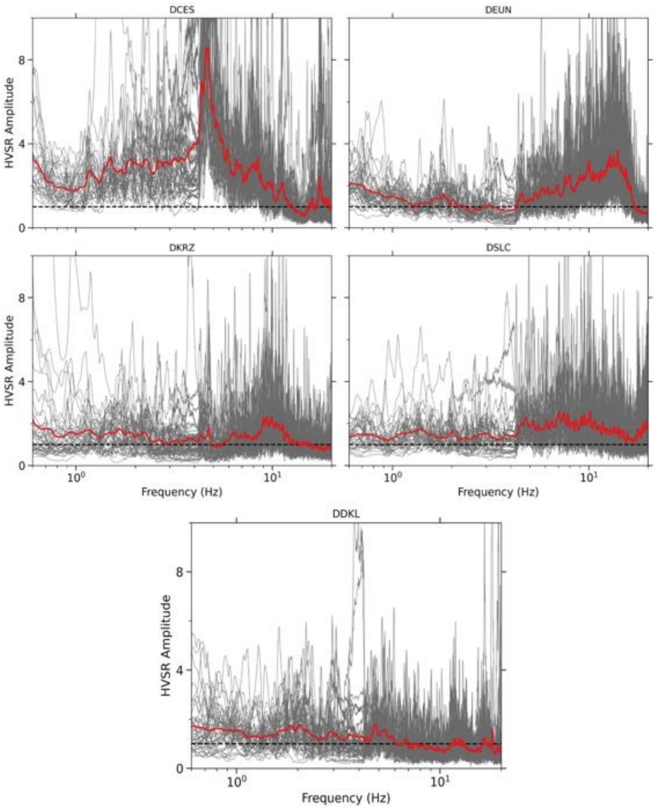

Figure 8. Site functions obtained by the horizontal-vertical spectral ratio method. The gray lines show the horizontal-vertical spectral ratio of each earthquake, and the red lines show the average H/V functions.

4. Discussion and Conclusion

A new Seismological Network (DEUNET) installed in February 2019 and started to record events, drastically improved seismic monitoring in Izmir as well as in Western Anatolia. Firstly, it supplies continuous earthquake records with high-quality data, thus it creates new understandings into the regional and local seismic activity. It allows us to determine the earthquake parameters of each event (location, focal mechanism, magnitude and depth) more accurately. In addition, the new network will provide an efficient tool for seismic analysis and crustal investigations. This network enabled us to obtain more accurate information about the mantle and crustal structures of the Izmir and its surroundings and to investigate the mechanism of the formation of the Western Anatolia.

The seismicity recorded by the network was analyzed to preliminarily results the seismic activity of the region. Our findings indicate a steady rate of seismicity up to the destructive event. The resulted seismicity maps show that the network can cover most of Izmir and Aegean Sea, in accordance with the purpose of establishing the DEUNET. Also, the network in the examined period has the capability to detect and/or locate local and teleseismic earthquakes. It also records microseismic activity, particularly magnitudes less than 3, which is not observed by the national stations in the area. Compared to other national networks, we focus more on the seismic activity of the region as we are a local seismic network. While doing this, unlike others, we do not fix our earthquake depths and we do it using a velocity model belonging to our region [30]. In addition, we keep the RMS of our earthquakes below 0.2 s compared to other institutions.

Since the installation of DEUNET Seismological Observation Network, we have been able to observe the destructive and intense earthquake activity in Izmir and its surroundings. Despite clipping our stations due to proximity to the earthquake we couldn't analyze the main shock and two major aftershocks, we reviewed other aftershocks and tried to learn about the mechanism of the earthquake. The distribution of aftershocks has progressed towards the east of Samos Island in time and continues around the Kusadasi Bay. Depth sections of longitude and latitude also gave results supporting the east-west extension of the Samos fault.

Western Anatolia has the potential to produce destructive earthquakes, exclusively in Izmir and its surroundings. With the help of DEUNET, we can present and contribute concrete data about the seismicity of the region. Our results enable more precise hypocentral locations in assigning zones of active tectonics. On the other hand, especially considering the differences in focal mechanisms in the offshore earthquakes, seismological studies that will be carried out integrated with marine seismic studies will reveal the unknown about the submarine fault structure.

The site transfer functions obtained by the H/V method reveal that there are different amplifications at different frequency values. It is thought that this situation changes depending on the ground characteristics of the station locations. However, to reach the actual amounts of these amplification values, it is necessary to investigate and develop the results with different methods. We plan to improve our site effect estimates and the site amplification functions determined more directly applicable for earthquake engineering applications, such as PSV (pseudospectral velocity) and intensity. This will allow us to predict ground motion in Izmir for a possible big earthquake and be useful for planning hazard mitigation and urban development studies for the future earthquakes close to the city.

Finally, we give some indications on the evolution and the future prospect for our seismic network. In the near future, DEUNET will be developed by the number of the station and merged data from our stations and other permanent national stations to obtain more accurate seismic activities and produce detailed models of crustal and mantle structures in this area. These will increase the performance of the network, improve the data quality, reduce the processing time, and help us in our development of an early warning system for Izmir. It has also been continued to determine more focal mechanisms of earthquakes of such a low magnitude that it would have been improbable to calculate it without this local network. Also, it can be concluded that the DEUNET will have an important place in helping the authorities to reduce earthquake risk in Izmir.

Ethics committee approval and conflict of interest statement

There is no need for an ethics committee approval in the current article.

There is no conflict of interest with any person/institution in the current article.

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Author Contribution Statement

All authors are project researchers (DEU- BAP 2018.KB.FEN.008) who contributed to the paper equally to this manuscript, and they have accepted responsibility for the entire content of this manuscript and approved its submission.

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