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Spectral Noise Analysis of Broad Band Stations in The Local Seismic Network of The Biga Peninsula

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Abstract: *Background noise analysis is a fundamental component of spectral analysis in seismology. This method involves the evaluation of continuous vibrations recorded at the earthquake stations. This approach is significant for determining station performance and increasing the reliability of obtained seismic data. The Biga Peninsula is a region of particular concern because of its active tectonic structures and elevated seismic activity in recent years, classifying it as one of Turkey's significant seismic zones. In the aftermath of February 6, 2017, Ayvacik earthquakes, a comprehensive earthquake observation network was established in the region, encompassing both temporary and permanent seismic stations. In this study, background noise analyses of the established stations were conducted, and the station performance was evaluated. This study examined the impact of high-amplitude seismic noise locations on the determination of earthquake recording station locations. The objectives of this study are threefold: first, to determine the background seismic noise level in areas where earthquake recording stations will be established in advance; second, to identify the sources of these seismic noises; and third, to create a more suitable network structure and obtain time series with high signal-to-noise (S/N) ratios. The noise models for stations established in Ayvacik and its environs, the Biga Peninsula, and the Edremit Gulf and its immediate surroundings were compared with low and high noise models (new high and low noise models). The analyses were conducted in frequency bands of 0.01–0.1 Hz, 0.1–1 Hz, and 1–10 Hz. For each station, the spectral power was analyzed to determine the spectral power density values for the maximum and minimum values. According to the findings, the presence of small-magnitude seismic events could not be discerned at the examined stations owing to elevated noise levels, necessitating the removal or relocation of these stations. The findings indicate that background noise analysis is imperative for station location selection and contributes to the estimation of regional seismicity with a reduced margin of error.*
Keywords*: Biga Peninsula; seismic network; noise analysis.*

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I. INTRODUCTION

The present tectonic structure of Turkey is marked by elevated levels of local and regional seismic activity resulting from the dynamic interactions between tectonic plates, which exhibit distinct kinematic properties. The North Anatolian and East Anatolian fault zones, the Aegean Region's opening regime, and the numerous faults and fault zones formed in their composition have been the sites of numerous destructive earthquakes, both historically and in the instrumental period, because of these movements. The Biga Peninsula, a region of tectonic significance in Turkey, is distinguished by its rich historical and instrumental seismicity data, distinctive tectonic features, and significant geothermal resources. The peninsula has been affected by various tectonic processes over different periods and maintains a high level of seismicity. The Biga Peninsula occupies a strategically significant region in Turkey, distinguished by its tectonic features and geothermal resources. The Edremit Gulf, located in the southern region of the peninsula, is a region of particular interest because of its distinctive characteristics of lateral displacement and its significance within the broader context of the Aegean rifting regime. The two regions have been impacted by various tectonic activities during different periods and have maintained their active seismic characteristics in the past and present. On a regional scale, the seismic events of 29, 155, 170, 543, 1737, 1855, and 1875 merit consideration, in addition to the instrumental period earthquakes documented in 1912 Mürefte (Ms=7.3), 1935 Erdek Bay (Ms=6.4), 1935 Çan-Biga (Ms=6.3), 1944 Edremit Bay-Ayvacık (Ms=6.8), 1953 Yenice-Gönen (Ms=7.2), 1964 Gönen (Ms=5.8), 1983 Biga (Mw=5.8), and 2006

Bandırma (Mw=5.2).As demonstrated by Kürçer *et al.* [1] and Perinçek [2], seismic activity in the Biga Peninsula and its surrounding region is indicative of continuous seismic activity in the area (Fig. 1).

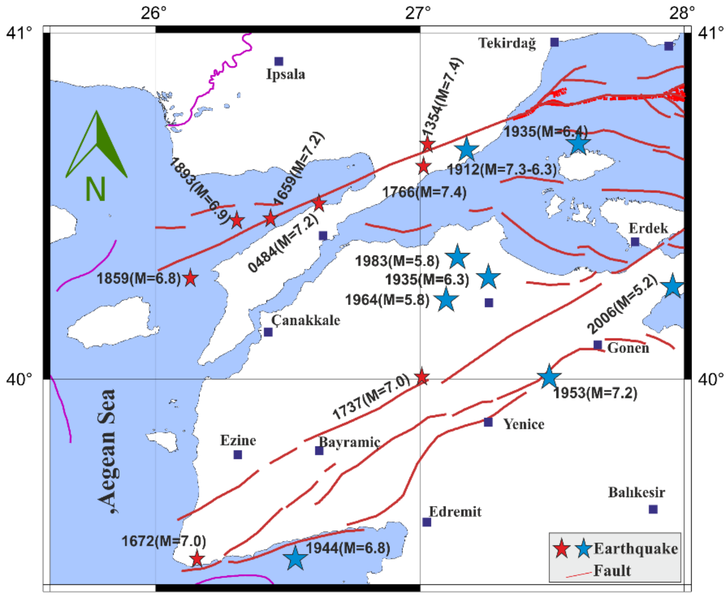

Fig. 1. Historical and instrumental period earthquake activity in Biga Peninsula (M>6.5)

In Ayvacık and its surroundings in the southwestern part of the Biga Peninsula (NW Türkiye), intense seismic activity began on January 14, 2017, with a magnitude of Mw=4.6, and continued with magnitudes of Mw=5.5 (AFAD), Mw=5.3 (AFAD), and Mw=5.4 (ÇOMÜ) on February 6, 2017, followed by a Mw=5.2 earthquake that occurred in the same region on February 20, 2019. To monitor these intense activities and conduct seismologically based studies of local and regional, shallow and medium-scale structural discontinuities, temporary broadband seismometer networks, in addition to national (KOERI-Kandilli Observatory and Earthquake Research Institute and AFAD - Disaster and Emergency Management Authority) earthquake stations, come to the fore in terms of resolution in obtaining earthquake parameters, such as noise level and seismic phase quality.

1.1 Theoretical Framework

In the spectral analysis of time series, the background noise spectral power density (PSD) method is a widely used approach for evaluating the signal quality of seismic stations and determining station performance and data reliability. This method characterizes ambient noise levels by calculating the power distribution in the frequency domain of continuous seismic records and is typically compared to global reference models such as Peterson's New High Noise Model (NHNM) and New Low Noise Model (NLNM) [3], thus identifying noise sources at stations (e.g., cultural or natural) and optimizing earthquake detection sensitivity.

The study of background seismic noise was initiated on a global scale by Brune and Olive [4]. Recent studies in our country emphasize the importance of selecting station locations where natural and cultural noise is minimized as much as possible for the establishment of such stations. As demonstrated in the works of Irmak *et al.*[5], Sevim *et al.* [6] and Altuncu *et al.* [7]. In this study, the primary objective was to ascertain the geographical distribution of earthquake recording stations, with a particular focus on locations that exhibit high-amplitude seismic noise. This study aimed to ascertain the background seismic noise level in areas where earthquake recording stations will be established in advance. This involves identifying the sources of seismic noise, creating a more suitable network structure, and obtaining time series with a high signal-to-noise (S/N) ratio.

The Power Spectral Density (PSD) is a fundamental approach used to examine the energy distribution of seismic signals in the frequency domain. According to the Wiener–Khinchin theorem, the PSD of a stationary random process [8] is expressed as the Fourier transform (1) of the autocorrelation function. Mathematically,

$$S_{xx} = \int_{-\infty}^{\infty} R_{xx}(\tau) e^{-i2\pi f\tau}\, d\tau \tag{1}$$

is defined as follows. where $R_{xx}(\tau)$ represents the autocorrelation function of the signal, and f represents the frequency. In practical applications, the PSD (2) is typically estimated from a time series of limited length by normalizing the square of the Fourier transform:

$$PSD(f) \approx \frac{1}{T}|X(f)|^2 \qquad (2)$$

Here, $X(f)$ represents the Fourier transform of a signal with length T. In seismology applications, the PSD plays a critical role, particularly in analyzing background noise and determining the dominant period of the ground. For this purpose, spectral estimation methods such as periodograms [9] and multitapers [10] are widely used to reduce the effects of limited data lengths.

II. DATA AND METHODOLOGY

Seismic background noise is a general time-series spectral process used to describe unwanted vibrations primarily generated by natural and/or cultural sources, such as human and technological activities. It also includes noise produced by the seismometer itself (instrument effect) and hardware-induced noise affecting the sensor owing to temperature and pressure changes. Each seismic source is defined by its frequency content. In the past, seismic noise was considered a nuisance; however, in recent years, an increasing number of researchers have begun to consider seismic noise. In the literature, seismic background noise is divided into two main categories: microseismic and microtremors [11, 12,13].

Noise levels originating from seasonal and cultural activities observed in areas where seismological stations are located (particularly owing to the increased population density during the summer months) are recorded at high levels in the cultural noise spectrum. Determining background seismic noise levels in advance in areas where earthquake recording stations will be established allows for the identification of the sources of this noise, enabling the creation of a more appropriate seismic network design and the acquisition of time-series data with a high signal-to-noise ratio (S/N). Noise from natural (wind, storms, ocean waves, rivers, and lakes) or cultural (industrial) sources disrupts the identification of phase amplitudes in seismograms, making detailed analyses difficult. In this project, it is crucial to establish stations with low seismic noise, where noise from sources other than seismic sources remains low. This allows events in both the low- and high-frequency bands to be emphasized, thereby creating time series with high S/N ratios suitable for seismic analysis.

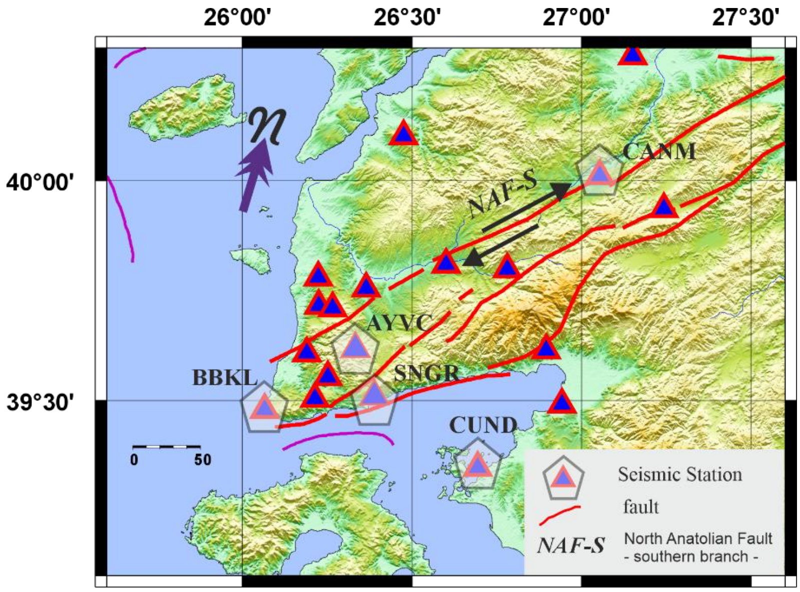

Fig.2. The locations of the temporary earthquake stations installed on the Biga Peninsula and the stations where noise analysis was performed. The stations mentioned in this study are shown within the pentagon

Noise models for seismic stations in Ayvacik and its surroundings, as well as those near the Biga Peninsula and Edremit Gulf, were compared with the low and high noise reference models defined by Peterson (1993) (New Low Noise Model (NLNM) and New High Noise Model (NHNM)). The spectral power density values for the established stations were examined, and the highest (NHNM) and lowest (NLNM) spectral power densities were determined. Accordingly, a noise model specific to the region was developed in the frequency band. Noise spectrum analyses were performed in three separate frequency bands: 0.01–0.1 Hz, 0.1–1.0 Hz, and 1.0–10 Hz. Power Spectral Density (PSD) analysis is a highly practical tool for evaluating noise in different bands at seismic stations. For this purpose, sample time series records of the raw time series for the E component of the SNGR station are presented for 1 h (a), 1 d (b), and 1 month (c). In addition to short-term earthquake-induced signals, the behavior of background noise at different scales can also be observed in the time series (Fig. 3).

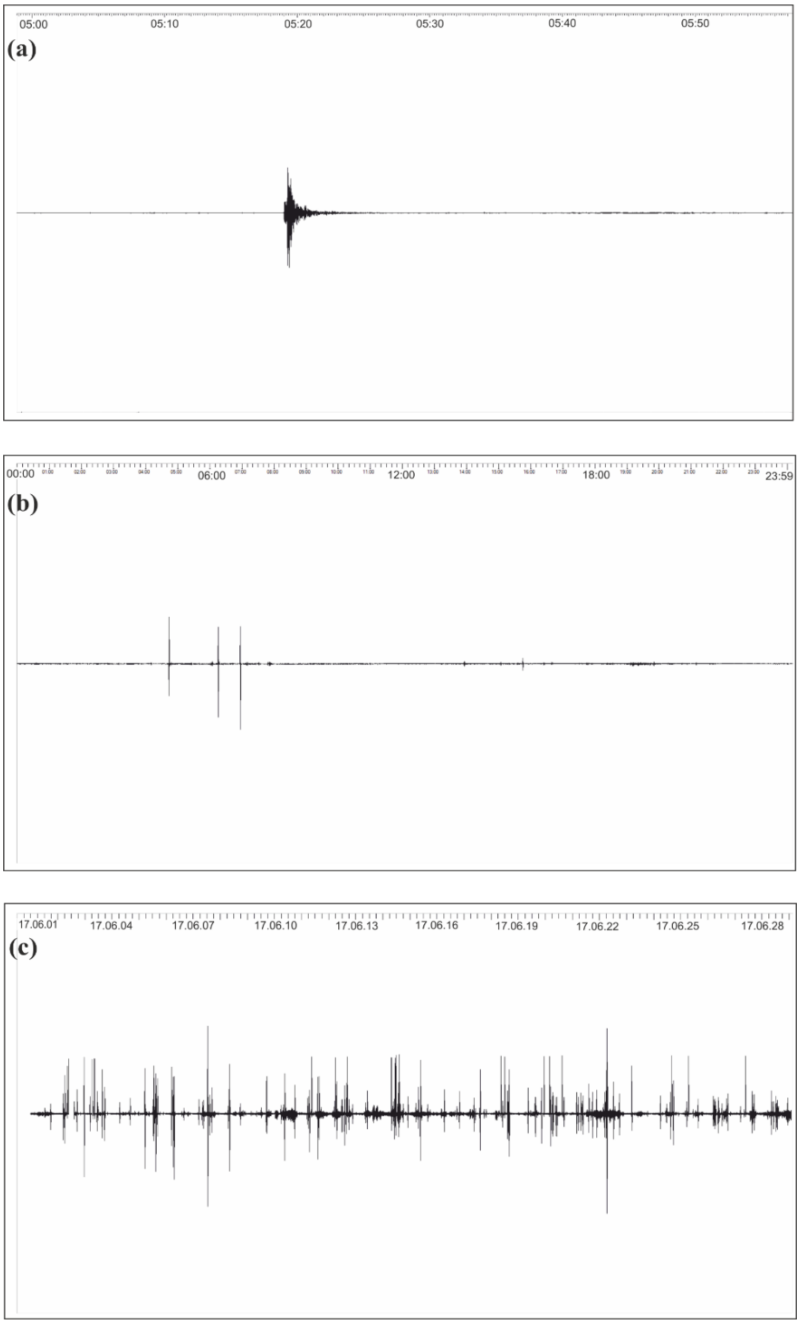

Fig. 3. Time series records belonging to component E of the SNGR station: (a) 1-hour, (b) 1-day, and (c) 1-month observations. Although the earthquake signal is clearly discernible in the short-term record, background noise becomes dominant at longer time scales

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The analyses revealed that the spectral power density graphs of some stations fell within the NHNM and NLNM limits, whereas the spectral power densities of other stations remained above the NHNM level for the entire duration. Ten temporary earthquake stations (ÇOMU) established in the region after the 2017 Ayvacik earthquakes continue to monitor ongoing earthquake activity. In addition to the 10 temporary stations operating in the region, five new stations were established, which began recording data (Fig. 2).

III. RESULTS AND DISCUSSION

The power density spectrum for a long-period seismometer established at the Center of Ayvacik is provided. The proximity of stations to urban settlements, which facilitates access to infrastructure services such as electricity and transport, may cause anthropogenic (human-induced) noise levels to be high in the spectral analyses. The AYVC station is located on the Ayvacik Peninsula, approximately 2 km from the epicenter of a foreshock that began on January 15, 2017, with a magnitude of Mw=4.6 (AFAD) and a main shock that occurred on February 6, 2017, with a magnitude of Mw=5. 3 (AFAD) on February 6, 2017, which caused severe and minor damage to some houses in the region, and the subsequent earthquakes that have continued to diminish in intensity to date. It is a very important station for monitoring both the 5.3 magnitude earthquake and the ongoing microearthquake activity. The seismic noise graph of the AYVC station (Fig. 4) was approximately -130 dB. However, it does not have sufficient S/N level to track micro-earthquake activity.

In contrast, the BBKL (Fig. 5), CUND (Fig. 6) and SNGR (Fig. 7) stations were closest to the coastline. All three stations were affected by sea waves owing to their proximity to the coast. However, BBKL has a higher noise level than the CUND and SNGR stations because of its proximity to the sea and exposure to excessive wind. However, the BBKL station was removed because of the high amplitude of fixed disturbing effects in the data collected during different periods of fieldwork. The SNGR station is built on the ground, consisting of basalt-derived rock. Although the station is far from local noise sources, it is approximately 200 m from the sea, and artificial factors near the station can generate noise during certain periods. Therefore, the noise level was approximately -140 dB in the 0.1-1.0 s period.

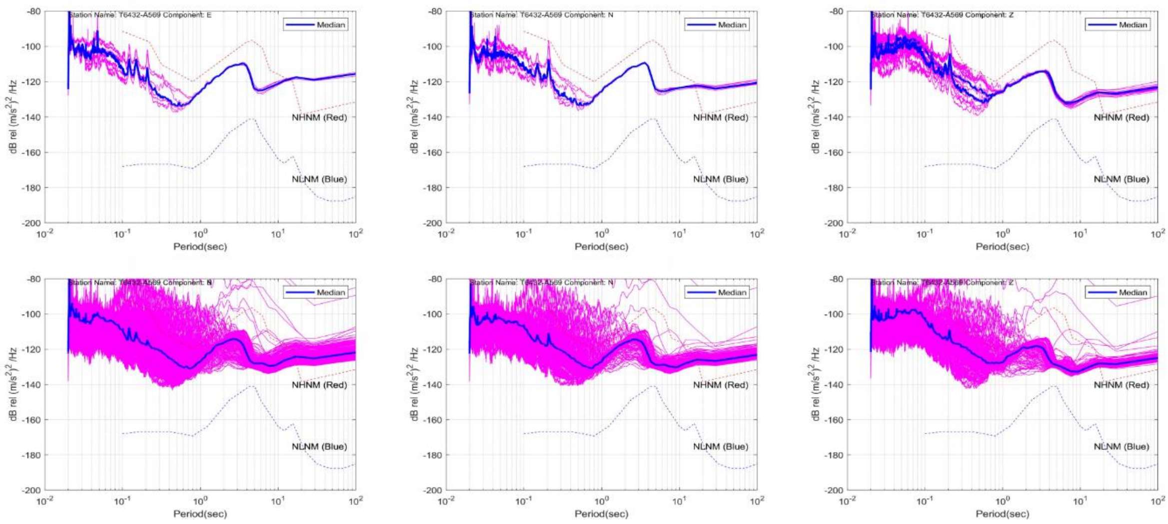

Fig.4. AYVC (Ayvacık) station Power Spectrum Density graphs of Z, N-S and E-W components for a day (upper graphs) and 1-month duration (Local site: Ayvacık Municipality building ground floor, site geology: Volcanic)

Daily and monthly Power Spectral Density (PSD) analyses for the AYVC station (Fig. 4) indicated that it is a station with a generally low noise level capable of producing high-quality recordings. The spectral levels observed in the short-period range (0.05–1 s) in all components (E, N, Z) are very close to the New Low Noise Model (NLNM) curve, demonstrating that the station is extremely reliable for observing local and regional earthquakes. In the medium period range (1–10 s), the spectral values are positioned within the NLNM and New High Noise Model (NHNM) limits, indicating that the station also exhibits a noise characteristic consistent with international standards in this band. In the long periods (10–100 s), an approach towards the NHNM was observed, particularly in the E and N components, indicating that noise increases owing to atmospheric conditions, ocean microseismic effects, or environmental factors. However, the Z component stands out with lower noise levels across all period bands and is considered the most reliable component at the station. Consequently, the AYVC station has high sensitivity, particularly in the 0.05–10 s period range and demonstrates reliable performance in terms of both earthquake observations and background noise analysis.

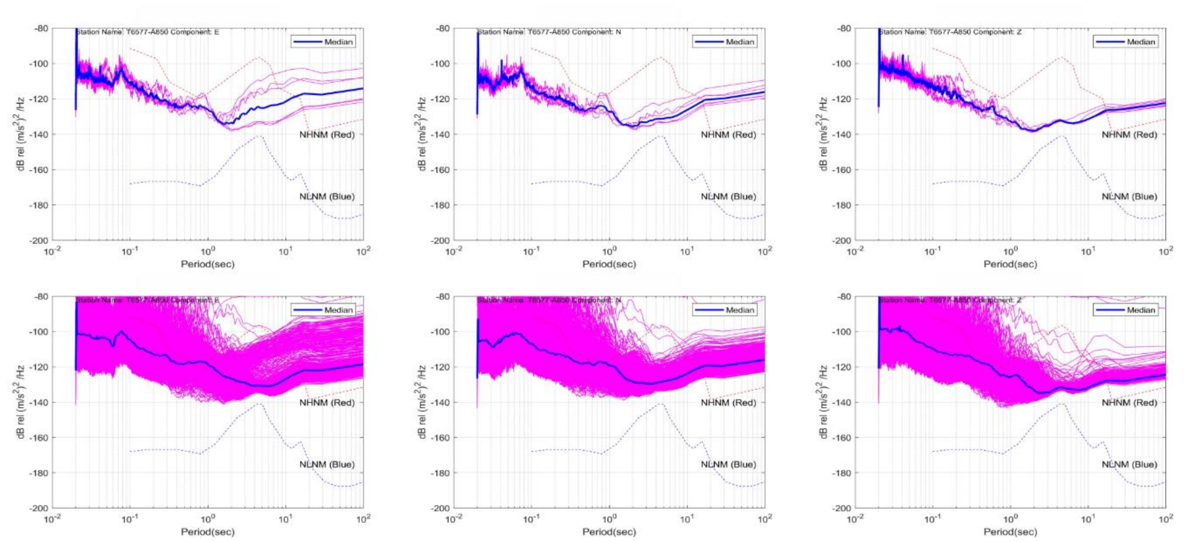

Fig.5. BBKL (Babakale) station Z, N-S and E-W component 1-month Power Spectrum Density graphs (Local site: Babakale village, site geology: Volcanic)

Daily and monthly Power Spectral Density (PSD) analyses for the BBKL station (Fig. 5) indicate that the station generally has a low noise level and operates within the internationally accepted New Low Noise Model (NLNM) and New High Noise Model (NHNM) limits. In the short period range (0.05–1 s), the spectral values for all components are close to the NLNM, indicating that the station has high sensitivity for local- and regional-scale earthquake observations. In the medium period range (1–10 s), the spectral distributions were more stable in the daily data, whereas in the monthly data, they exhibited a wider dispersion owing to environmental effects. In long periods (10–100 s), noise increases approaching the NHNM are observed in the E and N components, while the Z component stands out with a relatively lower noise level even in this band. In conclusion, the BBKL station provides reliable records, particularly in the 0.05–10 s period range and exhibits performance that requires consideration of the effects of environmental conditions in long-period analyses.

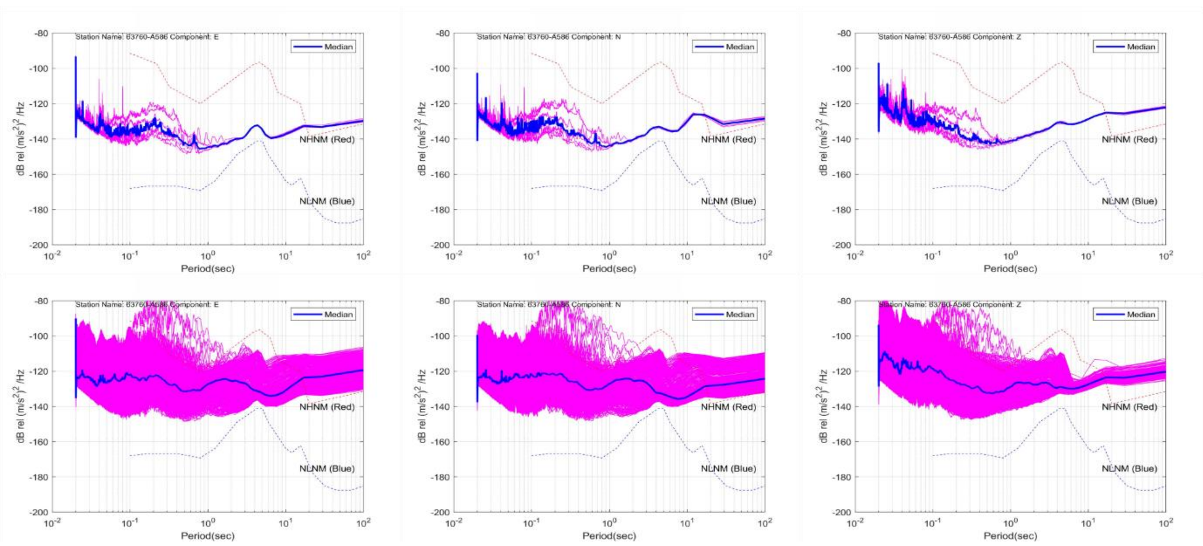

Fig.6. CUND (Cunda) station Z, N-S and E-W component 1-month Power Spectrum Density graphs (Local site: Cunda Island, seaside, site geology: Volcanic)

The CUND station (Fig. 6) generally performed well. The median PSD lines (blue) are positioned between the NLNM (low noise) and NHNM (high noise). This indicates that the station is of "medium-good" quality – not an ideal site, but acceptable for many regional/global seismic networks. In the 1-month data (bottom row), the median lines are smoother and slightly closer to NLNM because long-term data stabilize noise by averaging it out. In the 1-day data (top row), there were more fluctuations, likely due to daily events (e.g., local traffic or wind). The CUND station generally performed well. The median PSD lines (blue) are positioned between NLNM (low noise) and NHNM (high noise). This indicates that the station is of "medium-good" quality – not an ideal site, but acceptable for many regional/global seismic networks. In the 1-month data (bottom row), the median lines are smoother and slightly closer to NLNM, as the long-term data stabilize the noise by averaging it out. In the 1-day data (top row), there is more fluctuation, likely due to daily events (e.g., local traffic or wind). When evaluating the CUND station component by component, the one-day data showed peaks close to the NHNM in short periods (approximately -100 dB), with values in the microseismic band dropping to the NLNM. Long-term data is ideal for analysis. In the 1-month data, the band range was more stable and generally close to the NLNM. The typical cultural noise effect was dominant in the horizontal components. Therefore, cultural noise may require isolation at such stations when monitoring S-waveforms associated with horizontal ground motion. The situation for the N component is like that for the E component. In the 1-day data, noise can suppress the fundamental phases slightly more (reaching -90 dB in short periods). In the microseismic band, the fluctuation was greater. In the 1-month data, the average PSD is between NLNM and NHNM, and the seismometer responds well for long periods. The fact that this station is located right on the seashore but on a sloping, hill makes it possible to conclude that the difference between the E and N components is quite small. The Z component is the quietest of all components in all bands in the 1-day data, even in short periods, close to NLNM (-110 dB). It decreases to -160 dB over long periods. The 1-month data was almost perfect, and the variation was minimal. Therefore, the Z component is the strongest at the station. Vertical components generally receive less cultural noise, which indicates that earthquake stations in similar situations, such as CUND, will detect P waves well. This situation can be prioritized in teleseismic studies in the future.

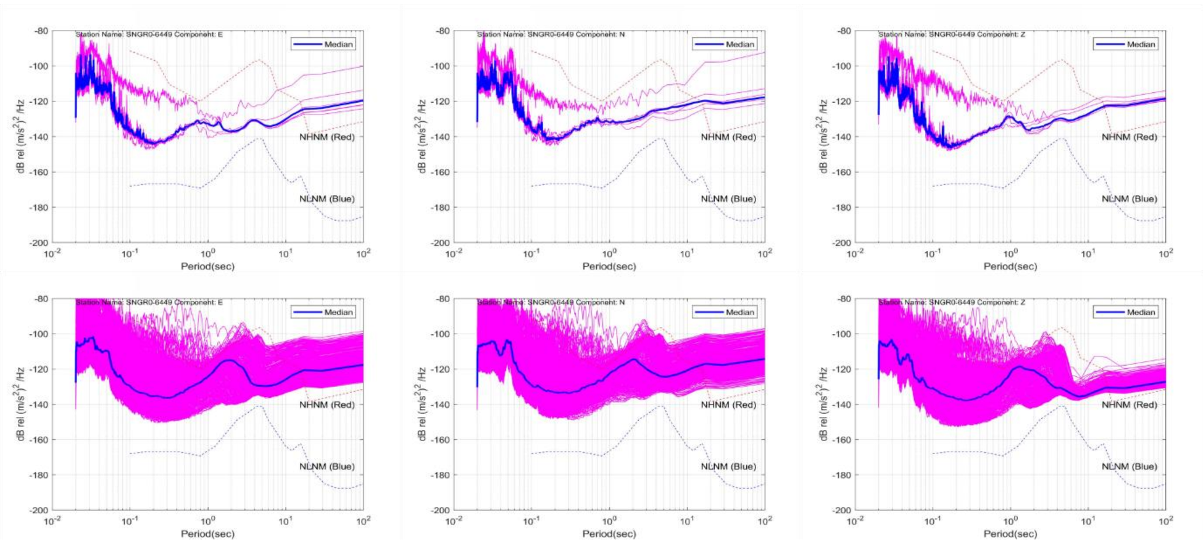

Fig.7. SNGR (Kocakoy-Tuzla village) station Z, N-S and E-W component 1-month Power Spectrum Density graphs (Local site: Private building ground floor, site geology: Sedimentary)

The daily and monthly power spectral density (PSD) curves for the SNGR station (Fig. 7), when examined across three components (E, N, Z), show that the station's overall noise level remains within the limits defined by Peterson (1993) for global Noise Models (NHNM – New High Noise Model, NLNM – New Low Noise Model). This indicates that the station is generally low-noise and operates healthily. In the short period (<0.1 s) range, the noise level is relatively high owing to electronic systems and environmental conditions, but the values remain close to NLNM. Therefore, the station can partially record small and local earthquakes (M<3) but has limited capability in detecting events with very low magnitudes. In the medium period (0.1–10 s) range, the median PSD curves were close to the NLNM and showed values significantly lower than the NHNM. This period band is the range at which the station has the highest sensitivity for regional-scale earthquakes, allowing for the reliable separation of the P and S phases. Over long periods (>10 s), a noticeable increase in the curves was observed because of the noise caused by microseisms. However, the values do not exceed the NHNM threshold, indicating that the station can be used to record teleseismic waves. For component Z, obtaining relatively lower noise values over long periods provides an advantage in detecting teleseismic P phases. Overall, the SNGR station has a limited recording capacity for local earthquakes, high sensitivity for regional earthquakes, and usable capacity for distant/teleseismic earthquakes. Therefore, it can be said that the station provides a reliable data source for both regional seismicity studies and research on the monitoring of teleseismic waves.

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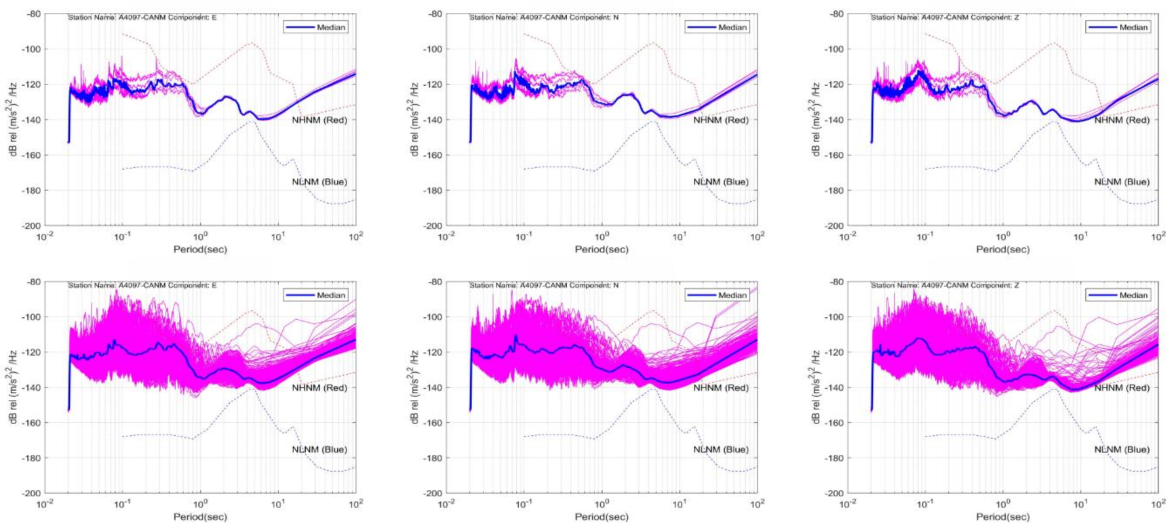

Fig.8. CANM (CAN town station Z, N-S and E-W component 1-month Power Spectrum Density graphs (Local site: Private building ground floor, site geology: Volcanic)

PSD analyses of the CANM station revealed that the station produced reliable and low-noise recordings, particularly in the 0.05–10 s period range. This band is suitable for monitoring both local and regional earthquakes. However, over long periods (10–100 s), a significant increase in noise approaching the NHNM was observed, particularly in the horizontal components. Although the Z component is relatively more stable, careful evaluation is required in this range. Overall, the CANM station demonstrated reliable performance for short- and medium-period recordings, whereas environmental conditions must be considered for long-period studies. The analysis revealed that the spectral power density graphs for some stations fell within the NHNM and NLNM limits, while at other stations, the spectral power densities were above the NHNM level. In this context, the CANM station stands out as a station with a low noise level (Fig. 8). The noise level measured in the 0.1–1 s frequency range was the lowest compared to other broadband stations on the Ayvacik Peninsula. The main reason for the low noise level was that the CANM station was located on volcanic units.

IV. CONCLUSION

Seismic background noise analysis is a highly effective approach for determining earthquake phases. This method ensures reliable wave analysis and facilitates the evaluation of the performance of the seismic network. The noise analysis of the broadband stations on the Ayvacik Peninsula indicates that, in general, seismic noise levels are elevated at periods of 1 s and below in most of the broadband stations within the seismic network. The background noise levels of the broadband seismic stations established on the Biga Peninsula and its immediate surroundings were examined to evaluate the station performance. The analyses indicated that noise levels exceeded the NHNM, particularly at stations located in proximity to residential areas, coastal zones, and transportation routes. This phenomenon complicates the detection of small-magnitude seismic events and reduces the resolution of the network. The elevated noise levels detected, especially at the BBKL and AYVC stations, constrained the microseismic monitoring capacity and necessitated the removal or enhancement of these stations. In contrast, the CANM, COMU, BGAM, and BURH stations exhibited low noise levels due to their location on volcanic rocks or in areas distant from cultural influences. This enabled the reliable monitoring of microearthquake activity. These findings demonstrate that geological ground characteristics, distance from the coastline, and human-induced noise factors play critical roles in station location selection. The heightened population density that characterizes the summer months, which, by its very nature, engenders an increase in cultural noise sources (i.e., traffic, industry, and tourism activities)—becomes more pronounced in spectral analyses. This, in turn, indicates that seasonal variability must be considered in seismic observations.

The proximity of stations to residential areas, intended to facilitate access to logistical infrastructure such as electricity and transportation, has resulted in an increase in the spectral levels of noise caused by human activities in these areas. Additionally, noise originating from seasonal and cultural events in the areas where the stations are located is observed as high-amplitude noise in the culturally derived noise band. This noise is particularly pronounced during the summer months, when there is an increase in population density. It is imperative that appropriate isolation conditions are meticulously implemented to minimize the noise levels of broadband seismic stations within the local seismological network. This network is meticulously operated to investigate micro-earthquake activity following the Ayvacik earthquakes. Conducting studies to enhance the performance of stations with analogous characteristics, such as AYVC, which are paramount for the monitoring of micro-earthquake activity, will have a reliable impact on the solution of earthquake parameters. The BBKL station was excluded from the study prior to its commencement due to the presence of high amplitude fixed disturbing effects in the data from disparate periods. In summary, the analysis of background noise is imperative for evaluating the performance of existing stations and for the selection of optimal locations for new stations. In this context, the findings obtained in the Biga Peninsula will contribute to determining seismicity with a lower margin of error for seismic networks to be established in the region in the future. In addition, it is recommended that isolation measures be enhanced at existing stations to enable more effective monitoring of micro-earthquake activity. Furthermore, for stations situated near residential areas, particularly from a logistical perspective, the implementation of supplementary ground improvement and isolation strategies is recommended.

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