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(Research Article)

Spatial and Temporal Variation of Seismic Ambient Noise in Tehran Region for Frequency Range 1-30 Hz

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Abstract

Because of the use of seismic ambient noise as a low-cost tool for researching subsurface structure and hazard assessments in recent decades, urban seismology has become an active research subject both with seismological objectives, as obtaining better microzonation maps in highly populated areas, and with engineering objectives, as the monitoring of traffic or the surveying of historical buildings. As a result, urban seismology has been used in the metropolis of Tehran, which is one of the world's most populated cities. The city is situated on the southern slopes of the Central Alborz Mountains on Quaternary alluvial deposits, and its southern section is situated on the northwest side of Central Iran's Great Desert, surrounded by active faults such as the Mosha Fault, North Tehran Fault and South Rey Fault.

By using cultural noises caused by human activities such as traffic, subway, concerts, and rituals in metropolitan settings, urban seismology explains underlying structures, enhances seismic hazard management, and zoning. As a result of the high level of noise created by human activities in Tehran, as well as the presence of subterranean structures in this metropolis, the necessity of urban seismology and seismic ambient noise approaches is clear. The data from Tehran's accelerometer networks that named Tehran Disaster Mitigation and Management Organization (TDMMO) and the Road, Housing and Urban Development Research Center (BHRC) which are equipped with a Guralp CMG-5T three component accelerometer and the power spectral density-probability density function (PSD-PDF) approach by PQLX software, which was made available to the seismologist community in June 2004 were utilized in this study to analyze the spatial and temporal fluctuations of seismic ambient noise in the frequency domain. For this purpose, the period of 10 December to 24 December 2020 was investigated. In addition, the effect of the Corona virus pandemic on the frequency and time domain level of seismic ambient noise was explored in period of 16 March to 26 March 2019 and 15 March to 25 March 2020. This period was chosen because the ancient Nowruz festival is in this period.

Finally, considering the energy level of cultural noise denoted by the large daytime/nighttime variation with large energy during working hours and much less during nighttime and weekends, most of the stations have been experiencing the lowest level of cultural noise between the hours of 3:30-4:30 AM across all three frequency ranges that include human movement, traffic and subway, and in terms of spatial variation, D011 station has been experiencing the lowest noise levels in all three frequency ranges due to its construction on a stone structure. Furthermore, investigations on the change of noise levels during the Corona epidemic revealed a drop of 1-4% and a rise of 1-15% for certain stations depending on their location in all three frequency bands.

Keywords: Seismic ambient noise, Power spectral density-probability density function, Spatial and temporal variations, Frequency range 1-30 Hz, Corona pandemic.

1. Introduction

Because of the present urban lifestyle in densely populated areas and the high level of noise caused by human activities, the use of noises, such as microtremors and microseisms, which are accessible at any place and time, may be an appropriate supplemental source for seismic surveys (Liu et al., 2014). Nonetheless, urban seismology has been an important study subject in recent decades, mostly for retrieving tomographic

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pictures and managing seismic risk. Noise sources may be classified into three period bands based on their frequency content: 1) short period (0.1-1 sec) signals known as microtremors, 2) intermediate period (1-30 sec) signals known as microseisms, and 3) long period (30-500 sec) signals known as "Hum" that are often created by ocean infra-gravity waves generated by storm-forced shoreward directed winds (McNamara & Boaz, 2004). Microseisms are the most continuous seismic signals on Earth and are mostly created by ocean-earth contact, although microtremors are a form of seismic wave induced by human and environmental activities (Okada & Suto, 2003). As a result, in addition to the expanding population in big cities during the last 65 years (Tehran statistics yearbook, 2017), transportation networks and equipment have developed, resulting in the production of noisy surroundings. As a result, urban seismology, as an effective technique, is critical for enhancing the seismic microzonation and reducing the danger of a sudden and unexpected earthquake in inhabited regions.

In this paper, the noise level changes in Tehran have been studied using the PSD-PDF method in the frequency domain, taking into account the economic and political situation of the city and its location in the central part of the Alpine-Himalayan seismic belt, surrounded by active faults such as the Mosha fault, North Tehran fault, and South Rey fault, as well as the existence of vast road networks and transportation systems. Tehran is located between 51 degrees and 3 minutes and 51 degrees and 44 minutes east longitude, and 35 degrees and 32 minutes and 35 degrees and 56 minutes north latitude.

2. Research method

To analyze time-dependent seismic noise changes as a function of period (or frequency) and spatial variations in the current research, the PSD-PDF in the frequency domain must be calculated. As a result, the time-dependent ambient noise spectrum from the Tehran Disaster Mitigation and Management Organization (TDMMO) and the Road, Housing, and Urban Development Research Center (BHRC) accelerometer network, which is equipped with a Guralp CMG-5T three-component accelerometer with a sampling frequency of 100 samples per second, is analyzed for two purposes. The first step is to investigate the spatial and temporal variations in noise in the frequency domain. Second, consider the effect of the Corona virus outbreak on noise reduction in the frequency and temporal domains. Figure 1 shows the location of the accelerometer stations used in this study.

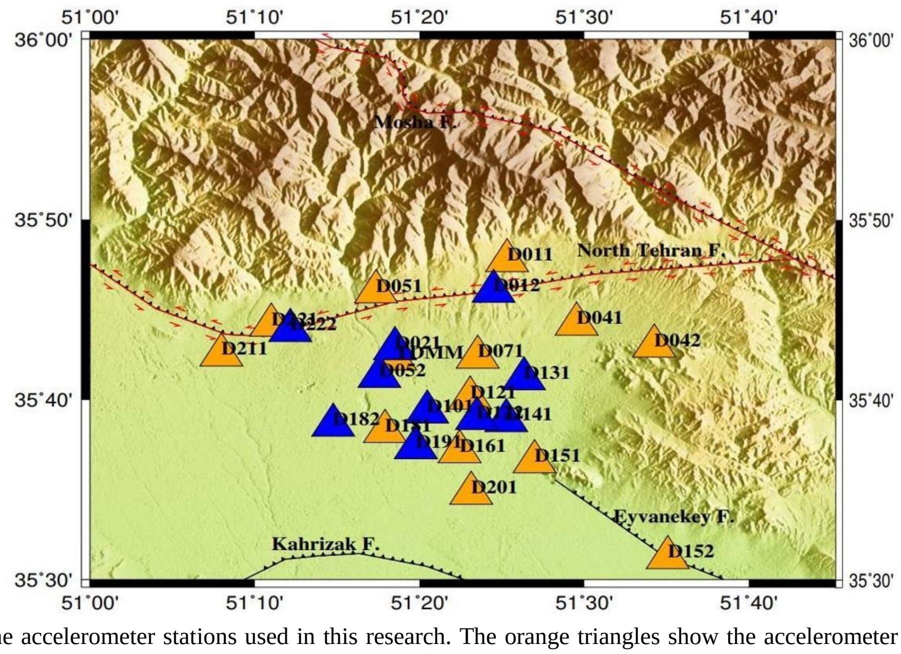


Figure 1. The accelerometer stations used in this research. The orange triangles show the accelerometer stations of the TDMMO network, and the blue triangles are the accelerometer stations of the BHRC, which are joint with the TDMMO. Red lines indicate faults with a strike-slip mechanism, and black lines indicate faults with a reverse mechanism.

The PSD-PDF approach can assess noise levels across a broad range of frequencies (0.01-16 Hz). The benefits of this new technique include: (1) offering an analytical picture of the distribution of noise levels rather than a simple absolute minimum, (2) assessing the overall health of the instrument/station, and (3) assessing the health of recording and telemetry systems (McNamara et al., 2005). The processing phases of this approach in Richard Boaz's PQLX program for analyzing the seismic station performance and characteristics, as well as data quality, are accomplished utilizing the instrument's waveforms and response files. The following are the frequency domain processing stages used in this technique (McNamara et al., 2005).

The data format must first be changed from gcf to miniseed, and then the continuous time-series for each station component is divided into 1-hour segments that overlap by 50%. To decrease the variation in the final PSD estimate, each one-hour time series record is broken into 13 pieces that are about 18 minutes long and overlap 75% of the time. To prevent spectral processing distortions, (1) mean and (2) long-period trend are removed in each segment, and (3) a 10% cosine taper is applied to minimize the effect of discontinuity between the beginning and the end of the time series, and processing is performed using an FFT (Fast Fourier Transform) algorithm. Finally, each one-hour time series segment is averaged to obtain a PSD. The estimated one-hour PSD is used to produce the PDF, which is a valuable tool for examining the energy distribution over the seismic spectrum as well as monitoring temporal changes to determine the likelihood of background noise for each station as a function of period for each station. (1) Frequencies are averaged in 1/8 octave intervals, and (2) powers are aggregated in 1-dB bins to calculate the PDF for each period. The resultant frequency distribution in each bin is then normalized by the total number of computed PSDs to get a PDF for each period.

Following the above stages, the temporal changes of noise and hour in proportion to the lowest noise level in the frequency domain are computed for each station, and maps of spatial changes are created for network stations using GMT software. SAC software is utilized for the second goal of this research, which is to investigate changes in seismic noise levels during the Corona virus pandemic in the temporal domain. The processing stages are as follows (Diaz et al., 2017).

After removing the instrument response, trend and mean from the data, a cosine taper is applied. Following that, a band-pass filter is applied to the data in proportion to the event being investigated, and the daily change in frequency ranges is detected using envelope. The sampling rate is reduced to one sample every 10 minutes at the conclusion of the processing courses.

3. Application of the method in the research area

Given the significance of accurate seismic noise study, including quantification of spatial and temporal variations for many seismic aspects such as the seismic network's ability to detect earthquakes, evaluate the performance of seismic equipment, and study the earth structure, calculating the PDF for the selected time period is critical.

Therefore, the PQLX tool is used to calculate PDFs that depict PSD shifts in the frequency domain based on continuous seismic recordings from 10 TDMMO accelerometer sites and five BHRC stations between 11 December 2020 and 25 December 2020. Also, the frequency ranges 2-6 Hz, 8-12 Hz, and 20-30 Hz, which are associated with human activities, traffic and the subway, respectively, have been analyzed to generate statistical data such as the mean and median of the PDF for each period. The frequency ranges listed above were chosen using the approach utilized in Diaz et al. (2017) investigations.

Noises from football events and music concerts were analyzed in Diaz research in attempt to forecast a typical pattern of people's movement signals. As a result, the Iran-Portugal football match was investigated in Tehran, and the frequency range 2-6 Hz for this seismic noise is stated. Furthermore, the frequency range 8-12 Hz was selected for the sounds created by urban traffic in Tehran because the envelope of amplitude is strongly connected to traffic activities in this frequency range, and recordings revealed higher energy during working hours than offhours and non-working hours. The data of the Mallard earthquake, which occurred in December 2017 with ML = 5.2, were utilized to calculate this frequency range. Because to the earthquake's aftershocks, individuals were compelled to flee their houses with their vehicles running. Finally, seismic stations near subway stations were studied in order to analyze the vibrations induced by subways and trains, and a frequency range of 20-30 Hz was selected (Aboalmaali, 2019).

Because major outliers in the data, such as earthquakes, system transits, instrumental glitches, and calibration pulses are eliminated from the derived statistical data, the median is chosen over the mean (McNamara & Buland, 2004).

Finally, the minimum median for each hour of the day over all three frequency bands by the 15 stations are listed in Tables 1, 2, 3 and the GMT software's spatial variation maps are also given in Figures 2, 3, and 4.

Table 1. Frequency range of 2-6 Hz.

Stations	Hours related to lowest median value of the PDF (Tehran time)
D011	03:30 - 04:30
D041	03:30 - 04:30
D042	06:30 – 07:30
D052	04:30 – 05:30
D101	03:30 – 04:30
D121	03:30 – 04:30
D131	03:30 – 04:30
D141	04:30 – 07:30
D152	03:30 – 04:30
D161	02:30 – 03:30
D181	03:30 – 04:30
D191	04:30 – 05:30
D201	03:30 – 04:30
D211	03:30 – 05:30
TDMMO	05:30 – 06:30

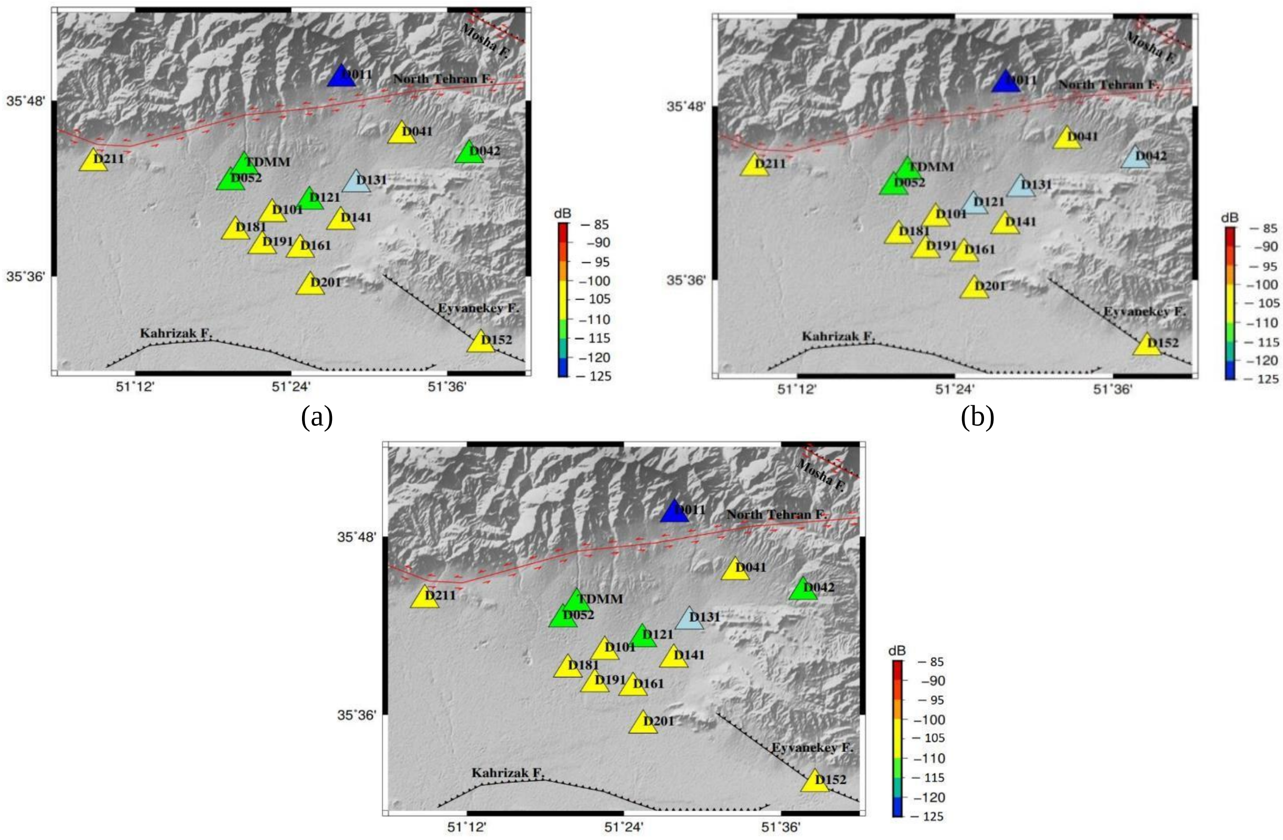
Table 2. Frequency range of 8-12 Hz.

Stations	Hours related to lowest median value of the PDF (Tehran time)
D011	02:30 - 03:30
D041	02:30 - 03:30
D042	03:30 – 04:30
D052	03:30 – 04:30
D101	02:30 – 03:30
D121	02:30 – 03:30
D131	02:30 – 03:30
D141	01:30 – 03:30
D152	01:30 – 03:30
D161	02:30 – 03:30
D181	03:30 – 04:30
D191	02:30 – 03:30
D201	01:30 – 02:30
D211	02:30 – 04:30
TDMMO	03:30 – 04:30

Table 3. Frequency range of 20-30 Hz.

Stations	Hours related to lowest median value of the PDF (Tehran time)
D011	02:30 - 03:30
D041	03:30 - 04:30
D042	04:30 – 05:30
D052	02:30 – 04:30
D101	02:30 – 04:30
D121	01:30 – 04:30
D131	04:30 – 05:30
D141	02:30 – 03:30
D152	01:30 – 04:30
D161	02:30 – 03:30
D181	03:30 – 04:30
D191	04:30 – 05:30
D201	02:30 – 03:30
D211	03:30 – 04:30
TDMMO	02:30 – 03:30

In Figures 2, 3 and 4, spatial variations were shown using GMT software proportional to hours connected to the lowest median value of the PDF at every given frequency range, and as shown, all three components of station D011 always experience the lowest level in these three frequency ranges.



(a) (b) (c)

Figure 2. Spatial variations of the lowest median of the PDF related to the frequency range 2-6 Hz for a) Z-component, b) N-component, c) E-component.

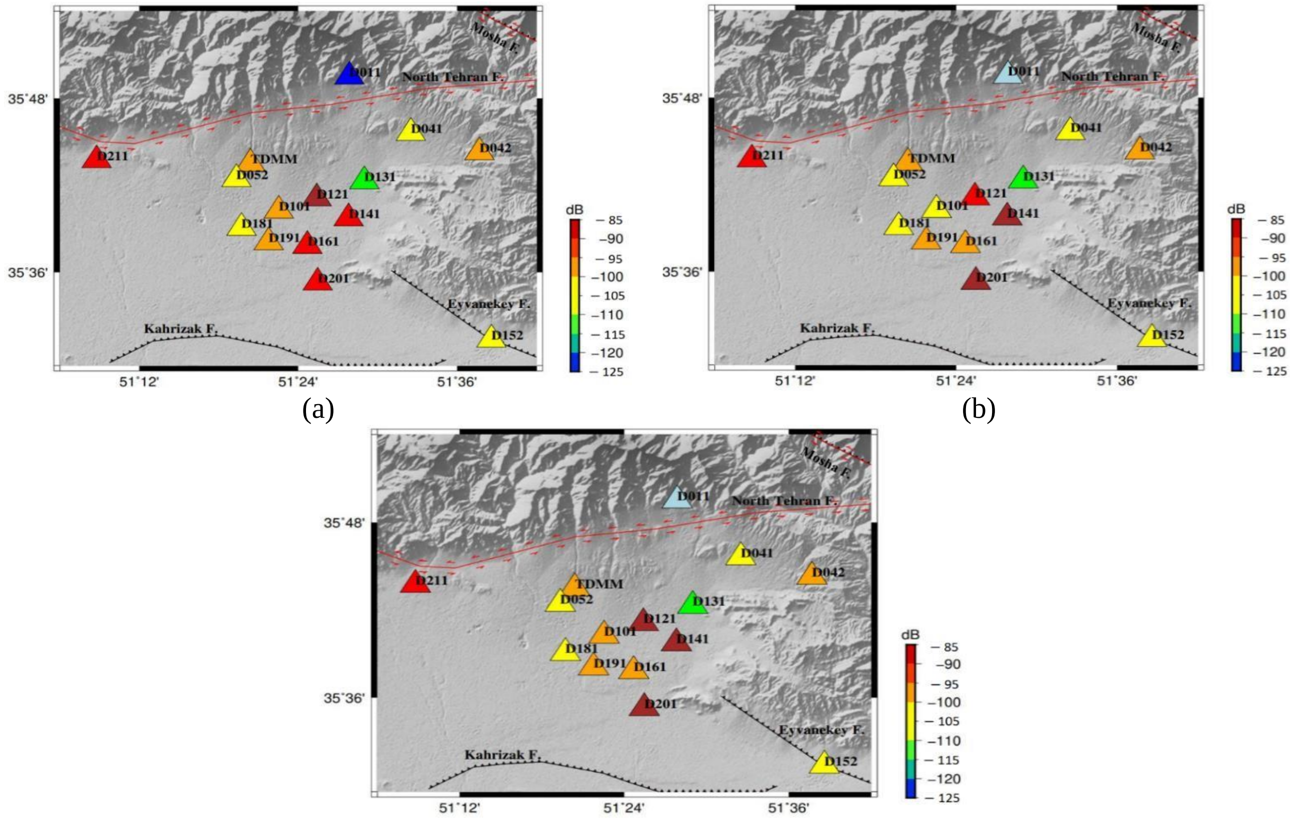


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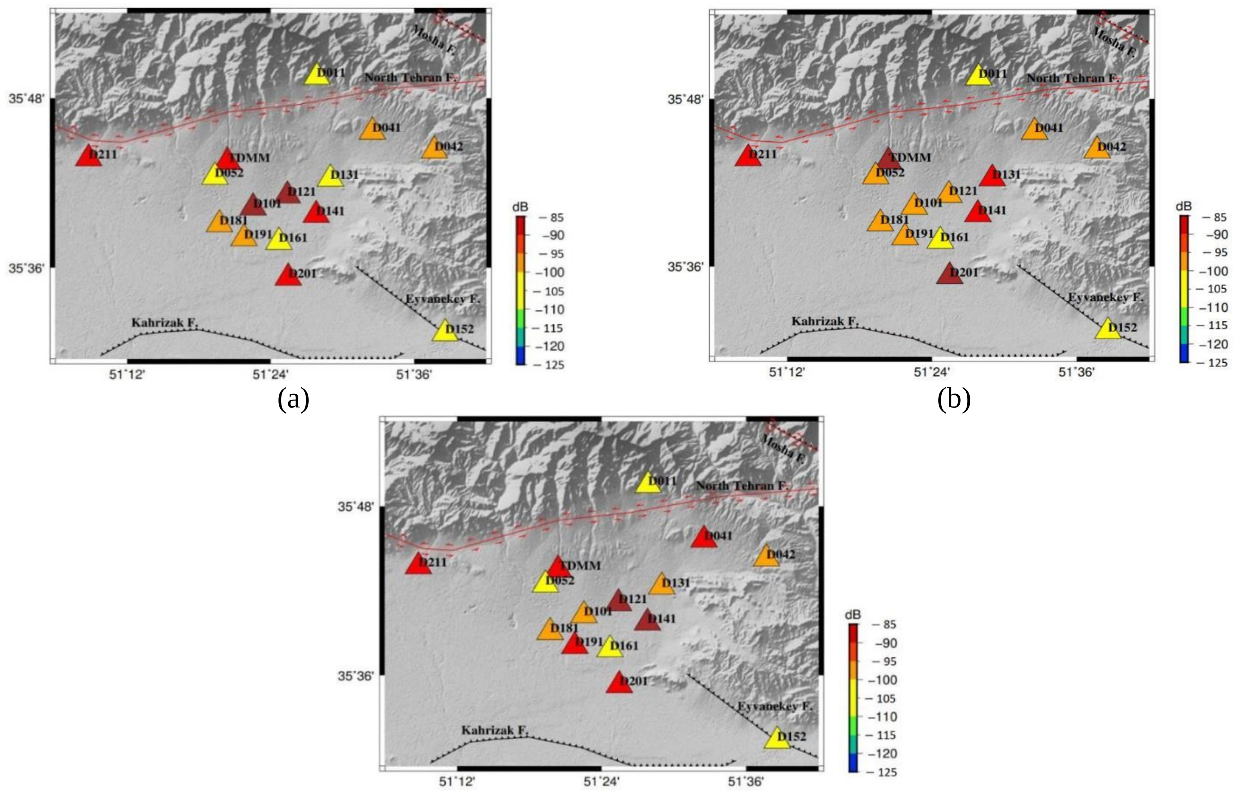
Figure 3. Spatial variations of the lowest median of the PDF related to the frequency range 8-12 Hz for a) Z-component, b) N-component, c) E-component.



(a) (b)

(c)

Figure 4. Spatial variations of the lowest median of the p PDF related to the frequency range 20-30 Hz for a) Z-component, b) N-component, c) E-component.

To explore the second aim, the fluctuation of the noise level in the frequency and time domain was calculated between 16-26 March 2019 and 15-25 March 2020. In frequency domain, the PSD-PDF method was used and an example of this type of map is shown in Figure 5 for the Z component of D011 station.

To analyze the influence of lockdown on the seismic ambient noise level, we report the median of the PSD in the frequency domain for eight TDMMO accelerometer stations in three frequency bands representing cultural noise in Figure 6. Variations in the vertical components of the PSD are shown since they were almost identical across all three components.

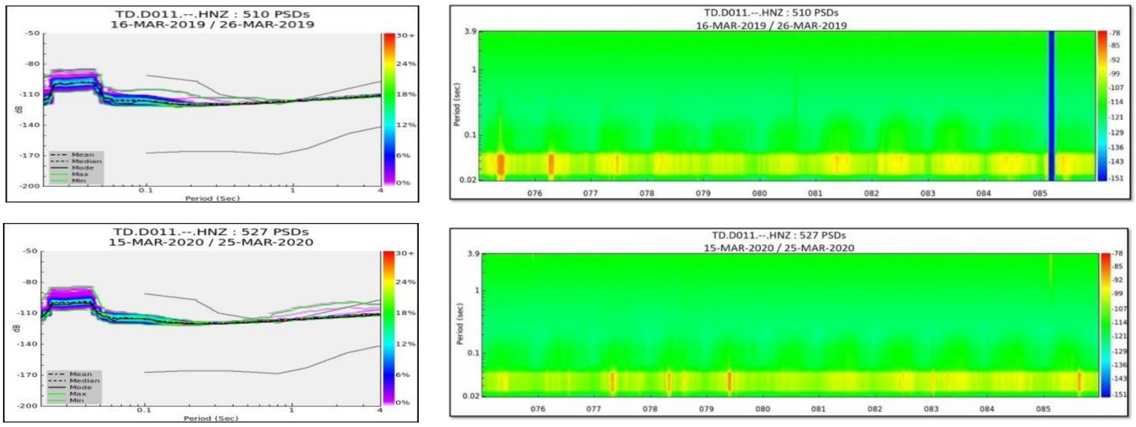
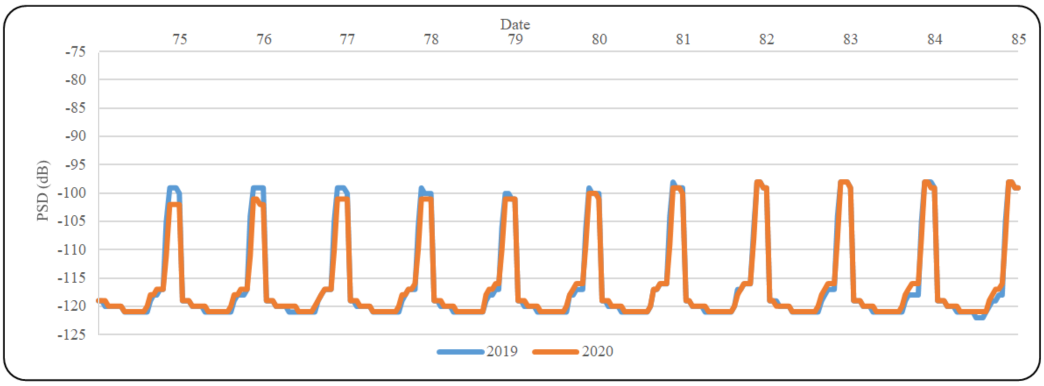


Figure 5. An example of PSD-PDF map obtained from PQLX software for the Z-component of D011station in the frequency domain.



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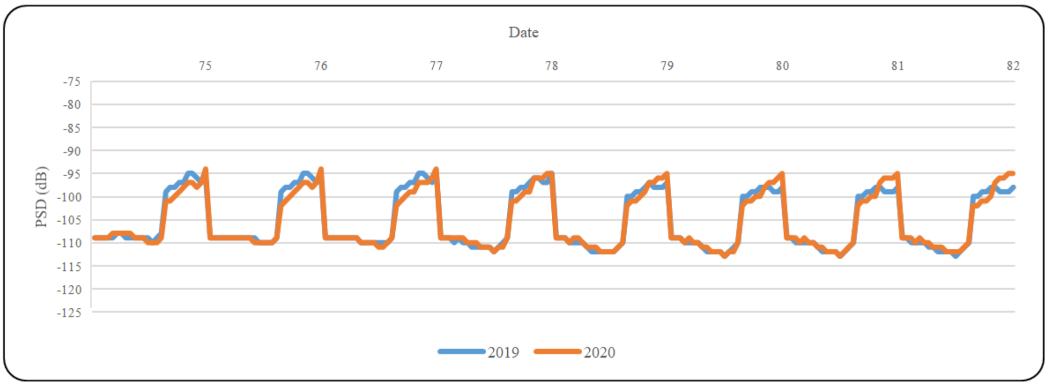

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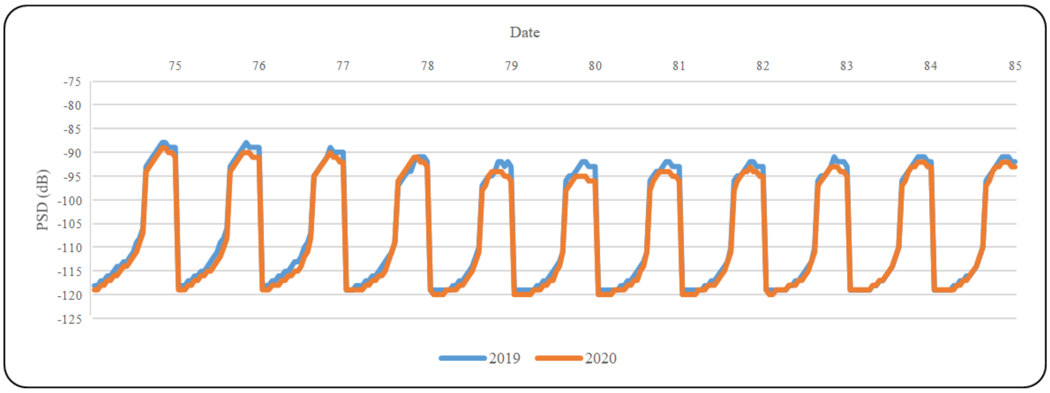
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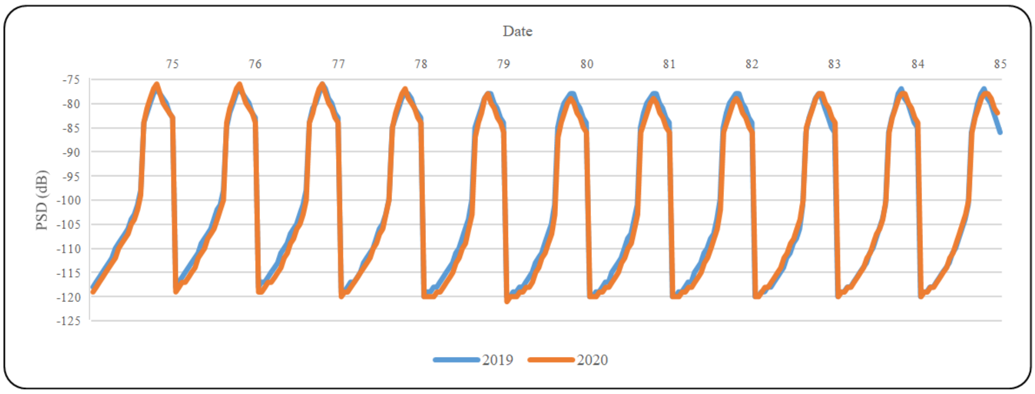
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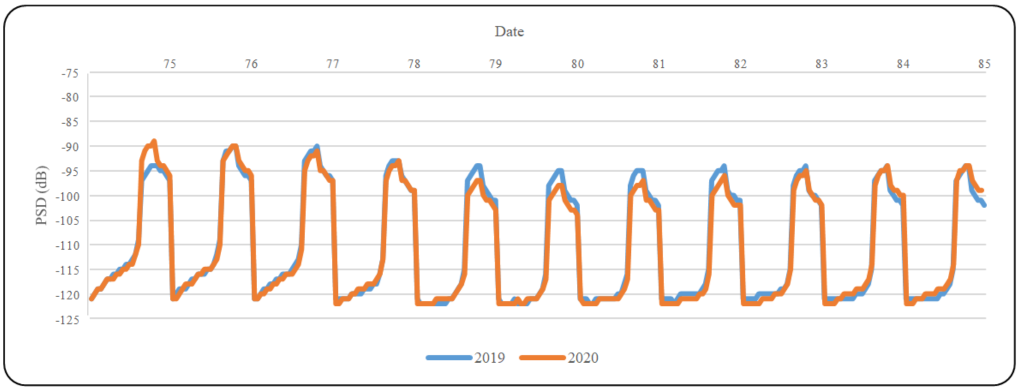
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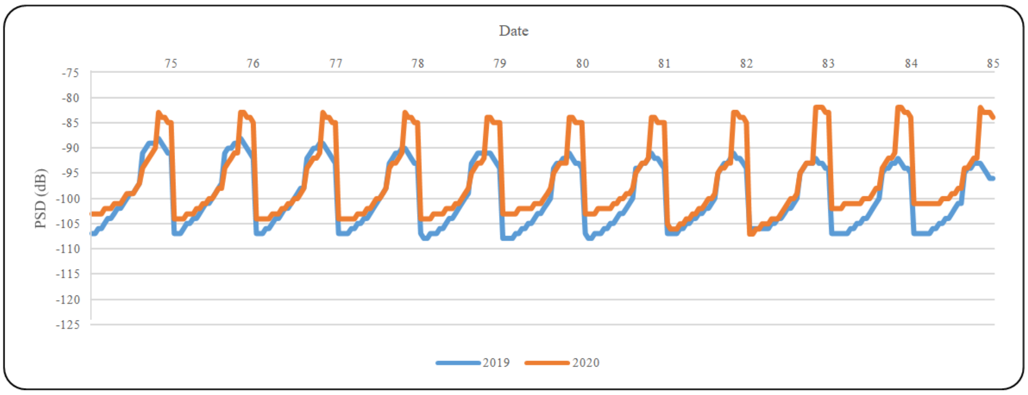
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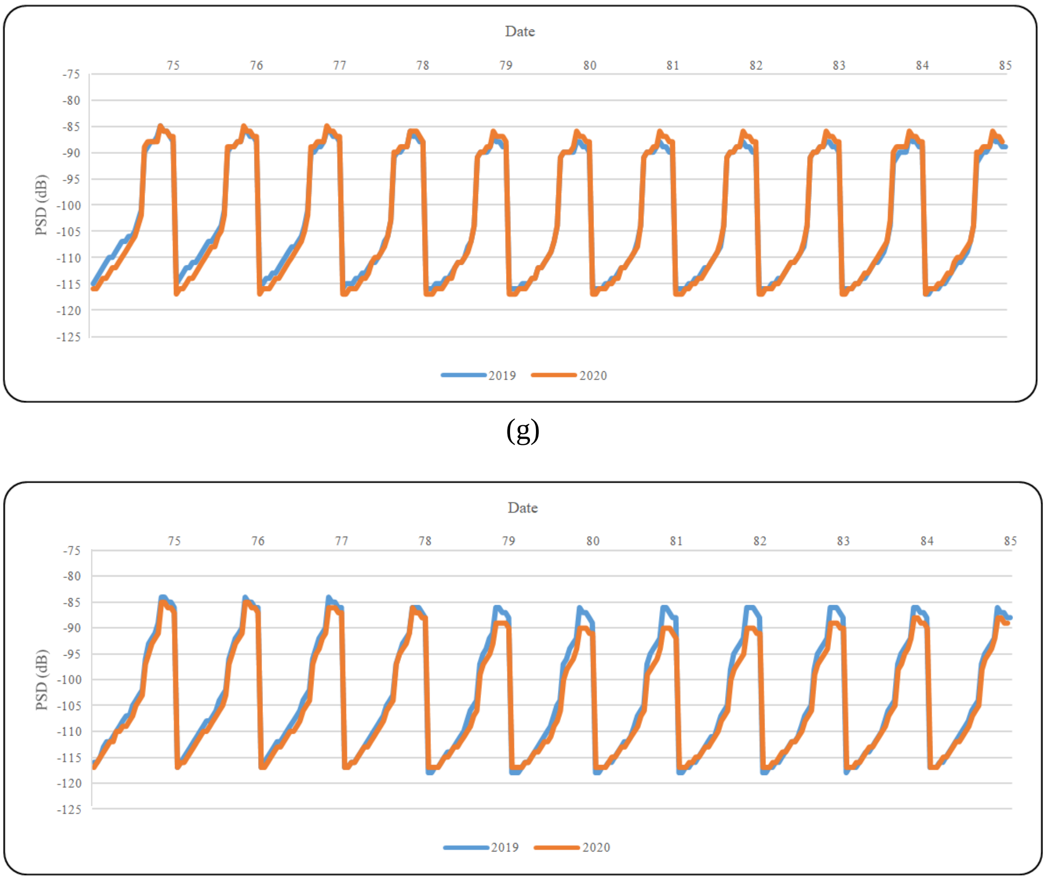


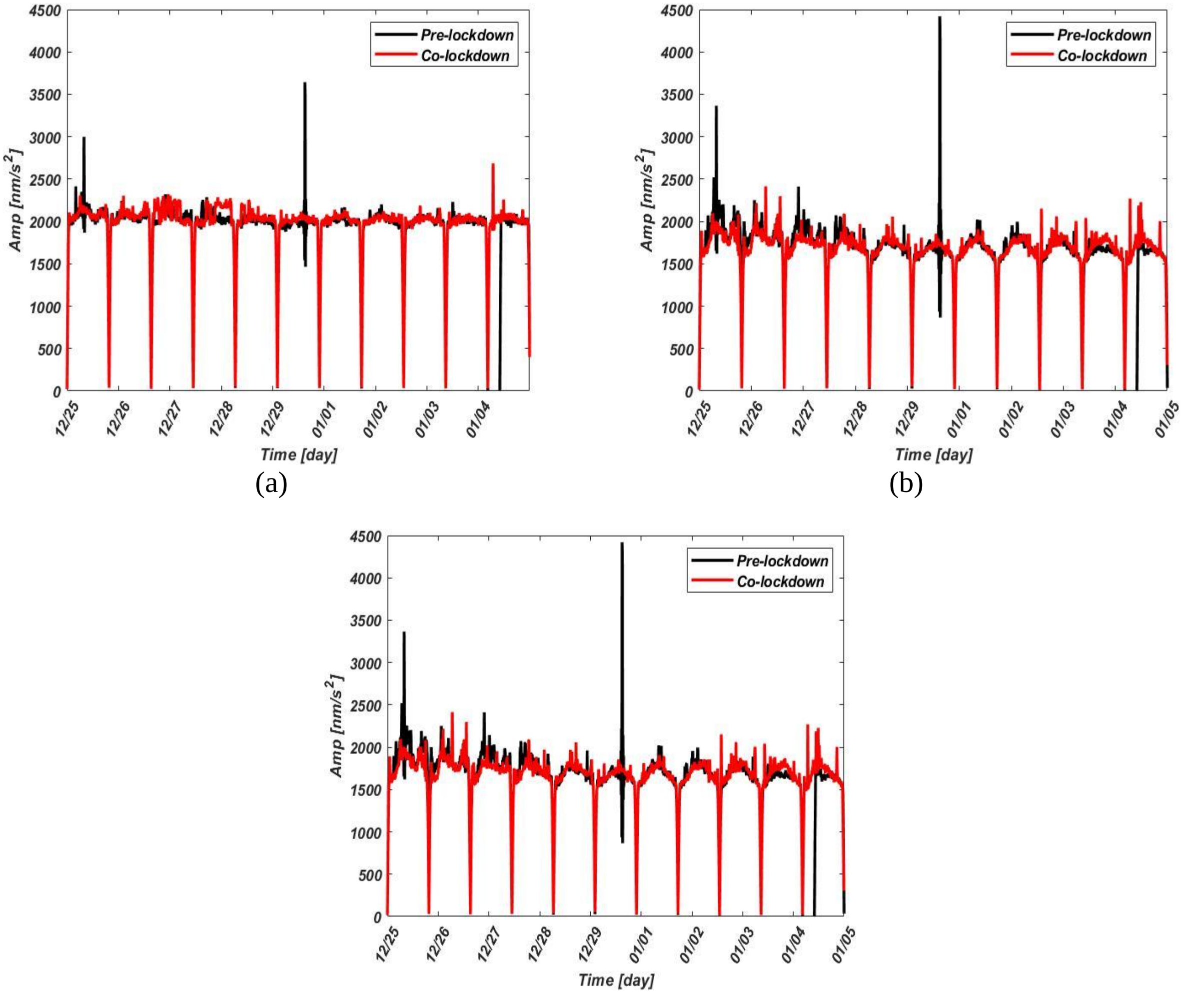
(g)

(h)

Figure 6. Variation of seismic signal during lockdown. The data are filtered at the frequencies 2-30 Hz and their temporal changes are presented as median of PSDs. Lockdown effects at (a) D011 station, (b) D041 station, (c) D071 station, (d) D121 station, (e) D151 station, (f) D181 station, (g) D221 station and (h) TDMMO station.

After studying noise level fluctuations during the Corona virus pandemic in the frequency domain, it was also analyzed in the temporal domain. As stated in the research method section, a band-pass filter appropriate to each event the researchers intended to investigate had to be applied to the data; thus, to study the variations in seismic ambient noise caused by people's movements, traffic and subway, a band-pass filter in the frequency ranges of 2-6, 8-12, and 20-30 Hz is required. Finally, the findings of time domain processing for all three frequency ranges and all three components of the D011 station, which is one of the TDMMO's accelerometer stations at Jamshidiyeh Park are shown in Figures 7 to 9.

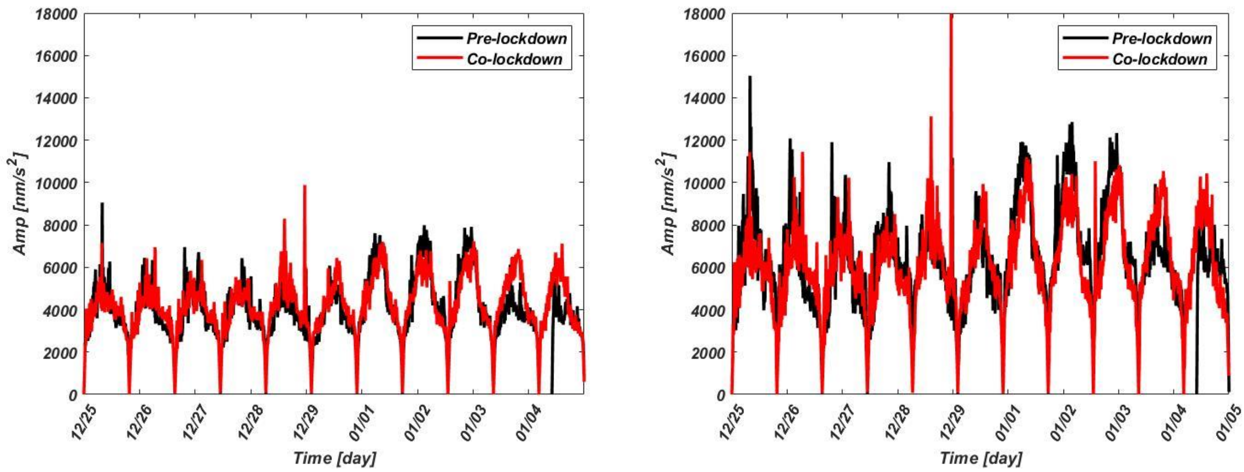
Figures 7 to 9 demonstrate that the amplitudes of all three components and three frequency ranges in the time domain for station D011 changed minimally. The median changes in the PSD of all three components in the three frequency ranges studied in the frequency domain are shown in Table 4 for eight accelerometer stations of TDMMO during the Corona virus pandemic, according to the aim of this study, which was to investigate variations of noise during the Corona virus epidemic in both the frequency and time domain.



(a) (b)

(c)

Figure 7. Envelope of accelerometer filtered between 2 and 6 Hz for pre-lockdown and co-lockdown for components (a) Z, (b) N and (c) E. Black line indicates the pre-lockdown and red line indicates the co-lockdown.



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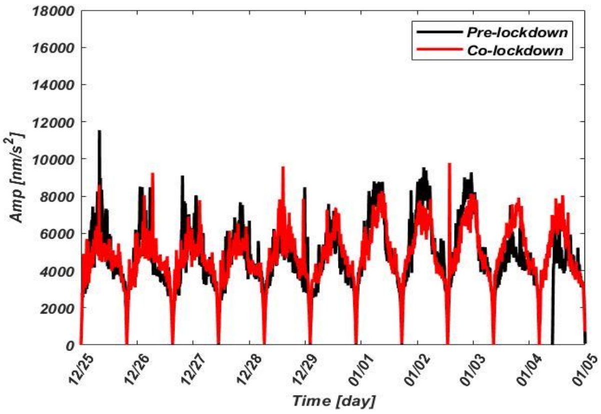
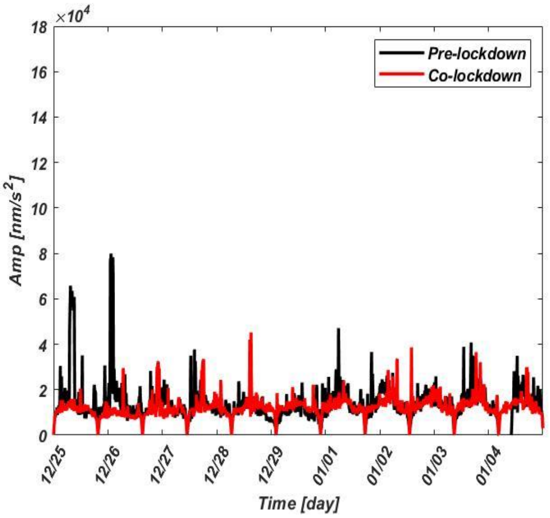


(c)

Figure 8. Envelope of accelerometer filtered between 8 and 12 Hz for pre-lockdown and co-lockdown for components (a) Z, (b) N and (c) E. Black line indicates the pre-lockdown and red line indicates the co-lockdown.



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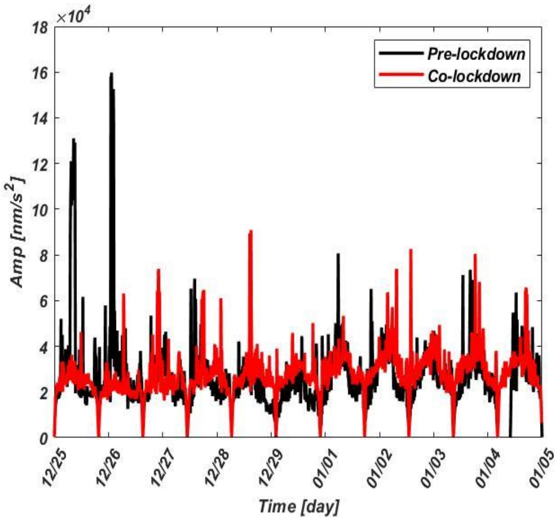

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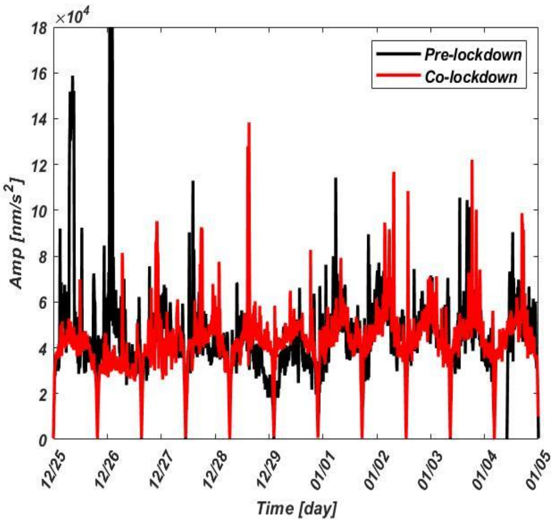

(c)

Figure 9. Envelope of accelerometer filtered between 20 and 30 Hz for pre-lockdown and co-lockdown for components (a) Z, (b) N and (c) E. Black line indicates the pre-lockdown and red line indicates the co-lockdown.

Table 4. Variations of noise level due to the Corona virus pandemic in eight accelerometer stations of TDMMO.

Frequency ranges (Hz)	Stations	Median changes of PSD (in percentage)
2-6	D011	+1 %
8-12		+1 %
20-30		-1-3 %
2-6	D041	+1 %
8-12		-1-3 %
20-30		-1-3 %
2-6	D071	-1-2 %
8-12		-1-2 %
20-30		-1-4 %
2-6	D121	-1-2%
8-12		-1-2 %
20-30		-1-2 %
2-6	D151	-1-2 %
8-12		-1-3 %
20-30		-1-2 %
2-6	D181	+1-4 %
8-12		-1-2 %
20-30		+6-15 %
2-6	D221	-1-3 %
8-12		+1-2 %
20-30		-1-4 %
2-6	TDMMO	-1-2 %
8-12		-1-3 %
20-30		+1-10 %

4. Discussion

Seismologists were provided a quiet seismic area to monitor earthquakes since the lockdown had a chilling effect on people's normal daily activities. As a result, researchers all over the world adore the longest and most constant global seismic noise reduction in recorded history, which has allowed them to discover delicate signals from underground seismic sources that would have been hidden in noisier eras. Therefore, studies on this problem have been conducted all across the world, and researchers have concluded that the impact of lockdown is noticeable in high frequencies (4-14 Hz) (Lecocq et al., 2020). They created a worldwide seismic noise dataset utilizing vertical component seismic waveform data from 337 broadband stations, but only 268 of them provided usable data, and significant reductions were discovered at just 185 of them. For example, a permanent seismic station in Sri Lanka observed a 50% fall in hiFSAN, while on Sunday evenings in Central Park, New York, hiFSAN was 10% lower during the lockdown compared to before it. The pandemic also had an effect on tourism; in Barbados, for instance, hiFSAN dropped by 45% following the vacation shutdown. This also happened in other nations throughout the globe, as seen in Table 5.

Table 5. Noise level reduction during lockdown due to the Corona virus worldwide.

Frequency range (Hz)	Case study	Reduction (in percent)
4-14	Seri Lanka	50 %
	Central park in New York	10 %
	Brussels (Belgium)	33 %
	Barbados	45 %
	Namibia	25 %
5-15	Gujarat (northwest India) (Singha et al., 2021)	1-13 %

The frequency range of 4-14 Hz for Tehran was also investigated in research done across the globe. Consequently, the vertical components of the TDMMO stations were reduced by 1-5%.

5. Conclusion

In the current research, the median PDF for TDMMO and BHRC stations was computed in one-hour time frames using PQLX software, and the lowest median for each station was obtained at a certain time and displayed using GMT software. As a secondary goal, the effect of lockdown on noise level was investigated. As a result, the highest noise level reduction due to human activities (frequency range 2-6 Hz) is associated with station D221 with about 3 dB, but stations near parks such as D011 (Jamshidiyeh Park), D041 (Police Park), and D181 (Ghaem Park) show an increase in noise levels in the early days of 2020, which corresponds to the official holidays. In the traffic frequency range (8-12 Hz), TDMMO station has the highest noise level reduction with about 2 dB, but D221station, which is about 100 m away from Shahid Kharazi Highway, has an increase in noise level, and in the subway frequency range (20-30 Hz), station D071 has the highest noise level reduction with about 3 dB, but stations TDMMO and D181 have an increase in noise level due to the presence of three subway stations nearby.

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