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VARIABILITIES IN URBAN AMBIENT NOISE BEFORE, DURING, AND AFTER COVID-19 LOCKDOWN IN THE PERUVIAN CAPITAL

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ABSTRACT. Recent studies have shown that urban ambient noise (UAN) decreased at many sites due to a slowdown in human activities brought by the SARS-CoV-2 (COVID-19) pandemic lockdowns. Such understanding is inferred from the historical record of the noise levels, which may also help us disambiguate noise sources as required for ambient noise tomography, microseismic and other seismic based studies. As UAN is site-specific, and its analysis enables passive situational awareness, therefore, in the present study, we analyzed the temporal variations in UAN before, during and after the social isolation in the metropolitan region of Lima, the capital of Peru, for the very first time. We used continuous waveforms recorded from February 1st to August 31st, 2020, at the Ñaña (NNA) broadband seismic station for the analysis. Results show the temporal changes occur in different frequency ranges; for example, at frequencies >1 Hz, significant changes in the mean daytime amplitudes are observed, which are absent in the lower frequency range (0.1–1, 1–3, 3–5 Hz). A maximum noise reduction of 37% is observed and should be considered for any future application of UAN. The results were verified by comparing with Community Mobility Reports (CMR) provided by Google using statistical change-point analysis.

Keywords: Urban ambient noise, root mean square, filtering, change-point analysis, COVID-19.

INTRODUCTION

Recent advances in the development of seismological methods and instrumentation allow the use of seismic information from active and passive sources in a wide range of frequencies that can be used to obtain detailed information about the environment, particularly in urban areas. In seismic monitoring, seismographic stations detect signals of interest, which may include seismic events generated by the internal dynamics of the Earth and by human and environmental sources, later referred to as urban ambient noise (UAN). UAN is an amalgamation of ubiquitous signals generated by vibrations on the Earth's surface (Condori, 2021) other than natural sources such as earthquakes. Its sources can either be natural and/or anthropic, such as the wind, the circulation of vehicles, cars, trains, and airplanes; movement of people, small vibrations due to construction sites, industrial machinery, very small magnitude local earthquakes, earthquakes in distant places, even fluctuations in temperature and atmospheric pressure, and terrestrial and oceanic tides that transfer energy to the Earth's crust (Pérez-Campos et al., 2021). Based on the frequency content, the ambient noise can be divided into two broad categories as microseisms (< 1Hz) and microtremors (> 1Hz).

UAN has been applied in many applications, such as in obtaining microzonation maps (Ashayeri et al., 2020), soil mapping (Wathelet et al., 2020) or monitoring traffic noise (Zambon et al., 2018), economic growth (Hong et al., 2020), or cultural events (Kil et al., 2021), global climate imprints (Stutzmann et al., 2009), engineering geology (Iannucci et al., 2018) geohazards such as landslides (Hussain et al., 2019), volcanos (De Plaen et al., 2019) and hydrology (Tribaldos and Ajo-Franklin, 2021). All applications of ambient noise require its stability over time. Therefore, impact assessment of these fluctuations in UAN on seismological studies is crucial to the fact that it allows for improving the level of detection of low magnitude earthquakes at local or regional scales.

In 2020, a slowdown in human activities was brought about by the onset of the SARS-CoV-2 (COVID-19) pandemic and worldwide lockdown, which changed the dynamics of large urban centers. Seismological observatories around the world have reported the effects of these on a wide range spectrum of UAN from seismometers located near cities (Dias et al., 2020; Gibney, 2020; Lecocq et al., 2020a; Piccinini et al., 2020; Yabe et al., 2020; De Plaen et al., 2021; Maciel et al., 2021; Ojeda and Ruiz, 2021). The significant alteration in seismic noise levels during the quarantine reached reductions of up to 50% in some of the world's metropolitan areas highlighting the human impacts on solid Earth and has increased the sensitivity of earthquake monitoring in some parts of the globe (Ścisło et al., 2022).

Consequently, discussions on whether lower UAN levels during COVID-19 lockdowns could improve the detection of small magnitude earthquakes were then initiated after the pioneering work of Lecocq et al. (2020a). The authors presented an example of the detection of an M5.0 earthquake at 15km depth SW of Petalan, during the daytime without any processing. Similarly, Godano et al. (2021) noticed an improvement in the low magnitude distant earthquake detection capability during lockdown periods in Italy, South California, and Greece. The authors concluded that the completeness magnitude remains unchanged. These studies further recommended the impact assessments worldwide in different site conditions.

In complying with the previous studies and considering is site-specific nature of UAN, and its analysis enables passive situational awareness, therefore, in the present study, we analyzed the levels of temporal variations in UAN before, during, and after the social isolation in the Metropolitan region of Lima, capital of Peru, and among the most populous cities in Latin America. For the analysis, we used continuous waveforms recorded from February 1st to August 31st, 2020 at the Ñana (NNA) broadband seismic station covering all stages of social isolations in a seismically active region. Results have been analyzed and discussed in reference to other similar studies at different frequency ranges.

2 MATERIAL AND METHODS

2.1 Study area and data

Lima is the capital city of Peru, and according to the National Institute of Statistics and Informatics (INEI), the Metropolitan of Lima has ~ 10 million inhabitants, being a city with high levels of urban noise whose sources are found in both within and in its surroundings (INEI, 2022). On March 6th, 2020, the first case of contagion by COVID-19 in Peru was confirmed, and the Peruvian government-imposed social isolation immediately in order to mitigate the spread of the virus. During the period of social isolation, different effects and mainly environmental impacts were likely to be observed that have manifested progressively as a function of space and time in each region of Peru. The concurrence of such conditions of high urban noise and social isolation has created an opportunity to analyze possible temporal changes in the field of UAN, as observed using the recording of seismic signals.

The database used for the seismic analysis corresponds to continuous waveform data acquired on 24-hour time windows (from February to August 2020), recorded by the Naña broadband seismic station (NNA) belonging to the Global Seismic Network (Bent, 2013) and managed by the Incorporated Research Institutions for Seismology (Figure 1). The station offers several advantages for the study of seismic noise variabilities before, during, and after the quarantine: i) its proximity to the metropolitan region of Lima, ii) high data quality (sensor model Streckeisen STS-1), ii) free data access and iii) continuity in the recording.

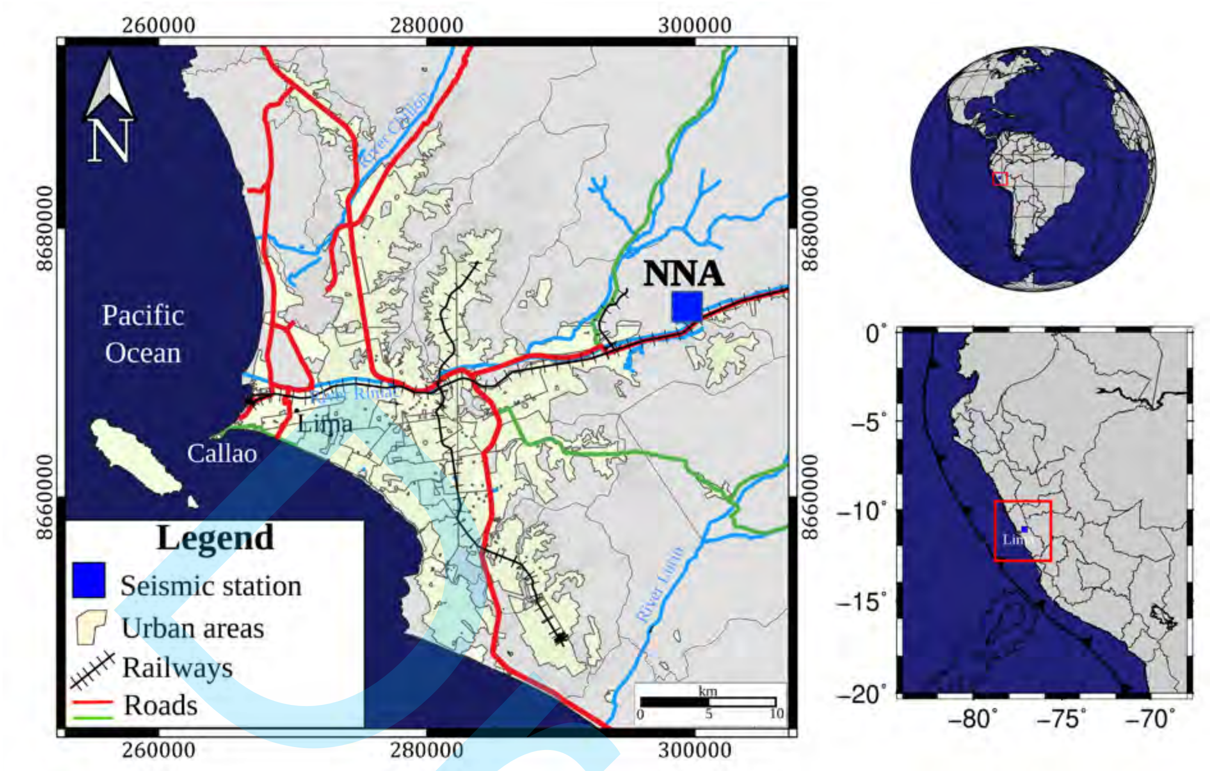

Figure 1: The insert map shows the location of Peru on the South American map, zoomed map of Peru with the boundaries of the metropolitan region of Lima in the red rectangle. The filled blue square represents the location of the seismic station NNA, at Ñaña.

2.2 Noise analysis

To characterize and determine the temporal changes of ambient noise, we used the methodology proposed by Lecocq et al. (2020a, 2020b). The vertical component seismic velocity records were used. The data processing was carried out in two stages: preprocessing and processing. The preprocessing included the instrumental response correction, removing the mean, and detrending the data. In the processing phase, the daily power spectral density (PSD) was calculated over 30-minute time windows, using the approach developed by Welch, (1967), here, each time window segment was converted to periodograms after applying the Fourier transform. Then, the displacement spectral power was estimated, from which the root mean square (RMS) of the normalized seismic amplitude was calculated. To see the temporal changes of the normalized seismic RMS amplitudes at different frequencies, different band-pass filters were applied with variable cut-off frequencies (e.g., 0.1-1, 1-3, 3-5, 5-10, 1-20, 4-

14, 4-20 and 10-30 Hz) (Figure 2). Finally, the RMS values were represented in a 24-h polar diagram to characterize the variation in average displacement during hours of the day (Figure 3). Furthermore, the evolution of noise displacements is also shown on an hourly grid representation from February 2020 to August 2020 (Figure 4c).

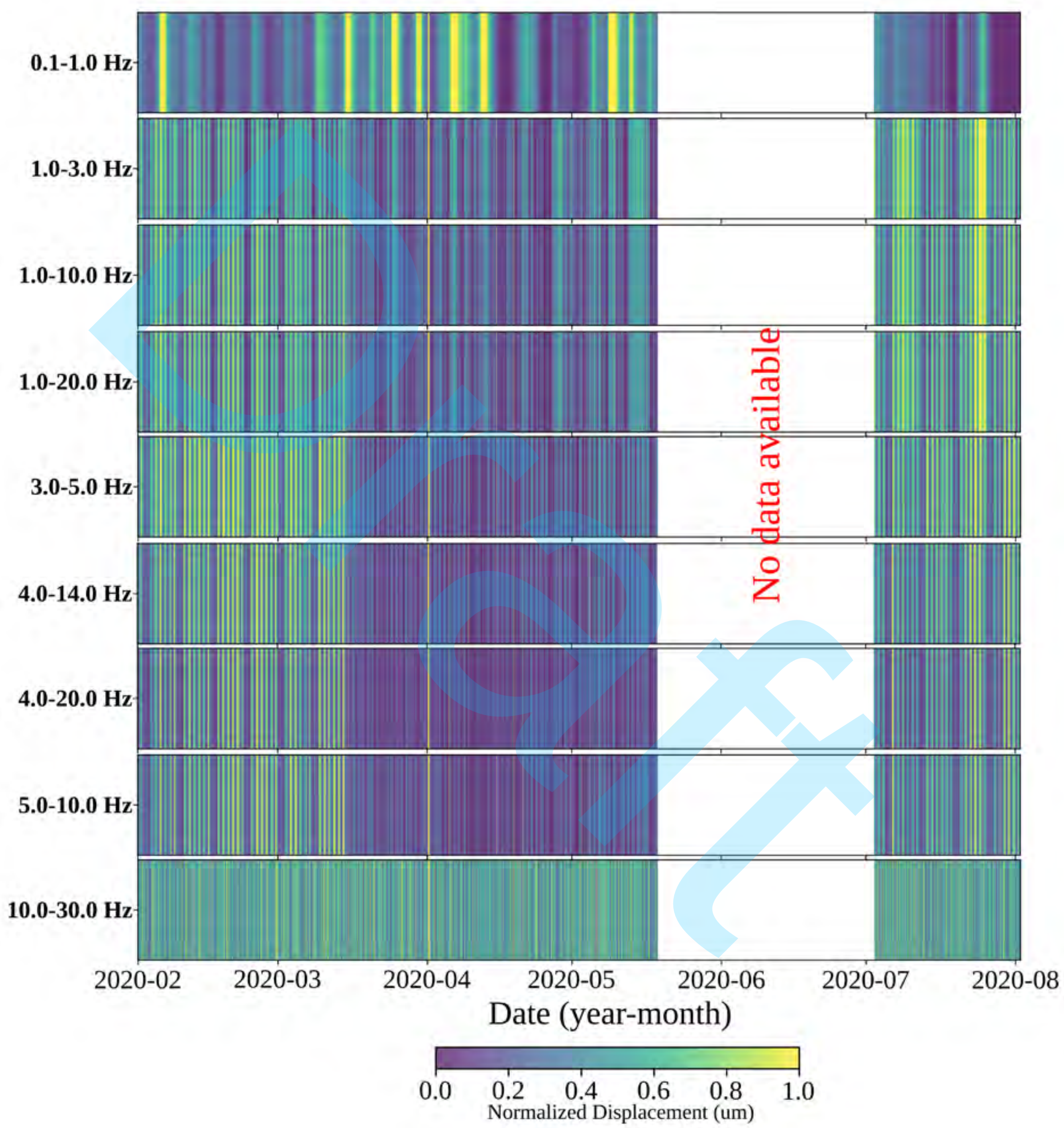

Figure 2. Normalized RMS amplitude of the vertical component of station NNA at nine different frequency bands. White space corresponds to data gaps.

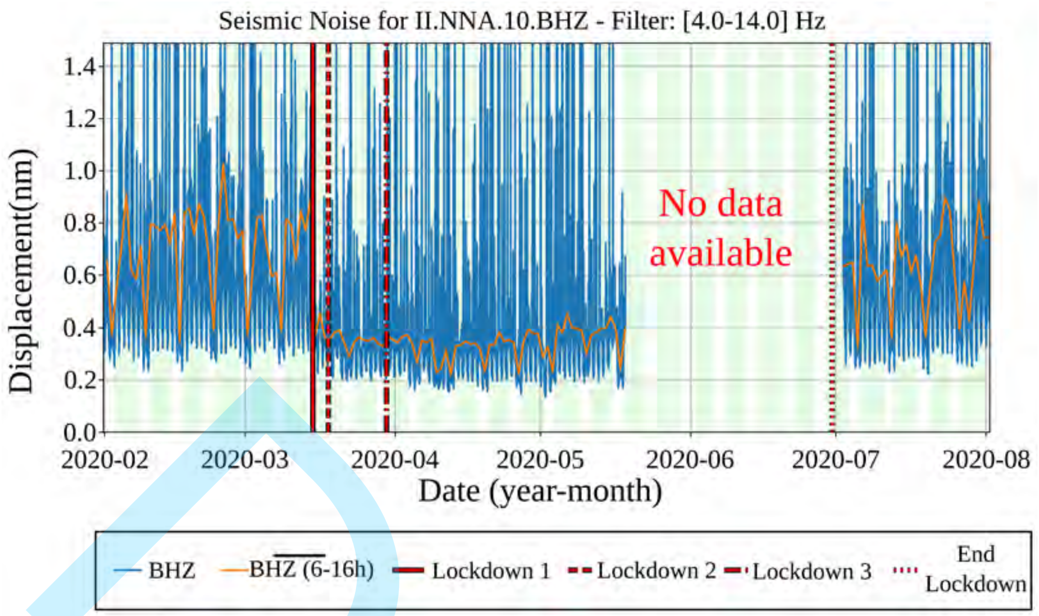

Figure 3. The blue line corresponds to the RMS amplitude time series of the vertical component, filtered between 4–14 Hz, and the yellow line corresponds to median daytime amplitude between 06:00 a.m. and 4:00 p.m. Gaps correspond to periods for which seismic data are unavailable. The vertical red lines indicate the curfew time.

2.3 Change-point analysis

The ambient noise RMS is compared with the sudden changes brought by the movement of people presented as Community Mobility Reports (CMR) (Google, 2020). These reports made use of smartphone data to detect people's mobility over various categories such as marketplaces, parks, workplaces and residential areas. CMRs provide valuable information on the changes that have occurred in response to people's mobility during the lockdown and are utilized for comparison with ambient noise RMS. A numerical approach for this comparison is adopted where a change between two time series is determined by the change-point analysis (CPA) using the Pelt algortihm (Killick et al., 2012). CPA is a technique designed to find changes in the underlying model of a time-series. It can be posed as an optimization problem, where a cost function is set to measure the uniformity of a time-series. Change-points are detected whenever the cost function is large. When two time-series are describing related phenomena, it is expected that their change-points occur at the same time. We used CPA to check whether the selected frequency ranges for UAN was identifying the same changes as LMR. It has been executed in the Python rupture library (Truong et al., 2020). A detailed explanation of the CPA approach and its application to UAN can be accessed at Maciel et al. (2021).

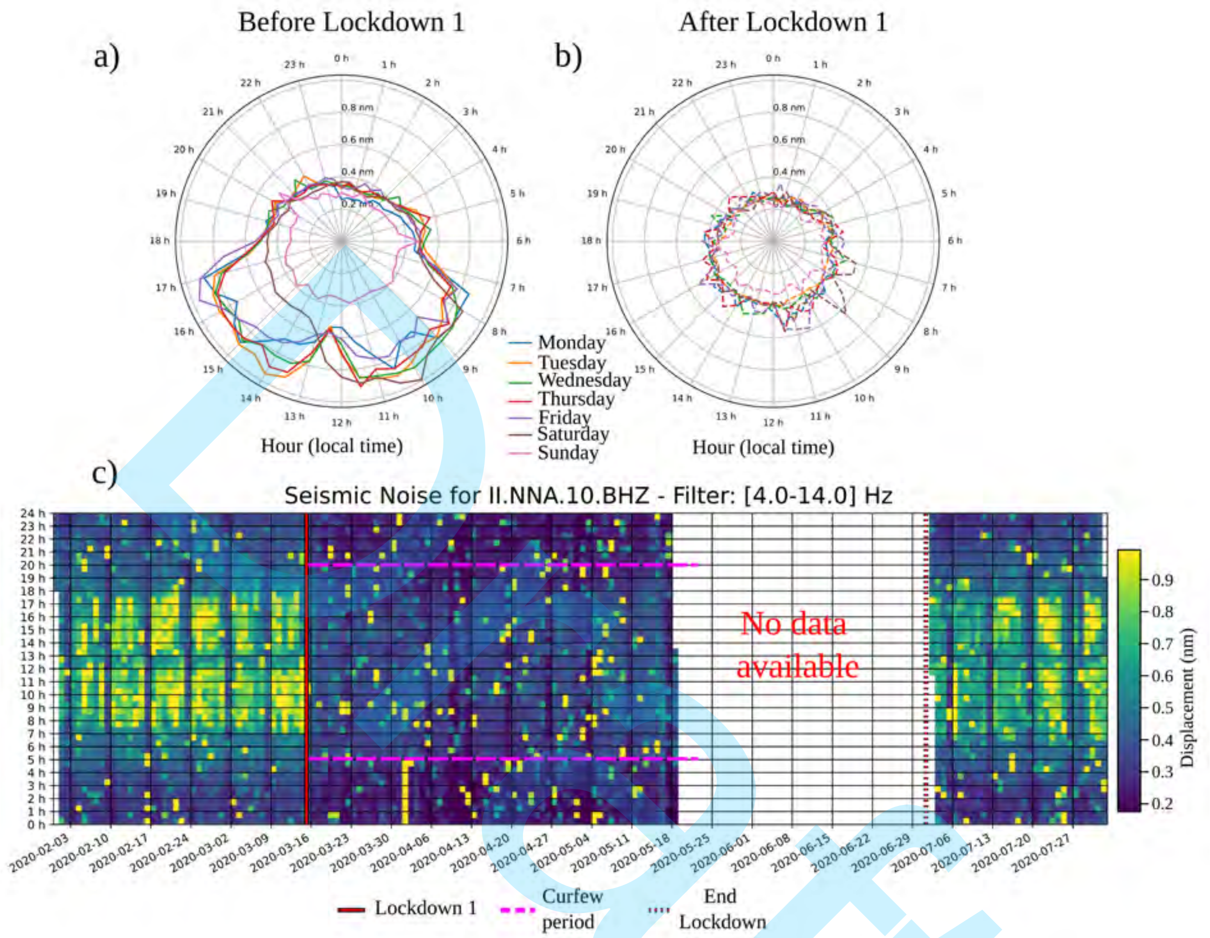

Figure 4. The clock plots show an average noise displacement variability over each day of the week for the period (a) co-lockdown 1 (January 1st to March 14) and (b) post-lockdown 1 (March 15 to August 1st), (c) displacement noise evolution is shown in an hourly grid representation. Gaps correspond to periods for which seismic data are unavailable. Horizontal dashed pink lines show the curfew period.

3 RESULTS AND DISCUSSIONS

Results are presented at different frequencies covering those hours of the day hosting high cultural activities (7 a.m. to 7 p.m.). In this way, the RMS amplitude variations for hours of the day could be marked where the COVID-19 lockdown was most effective. To clarify the differences in variation with frequency, we focused on nine different frequency bands consisting of both microseism and microtremor as well as broad frequency bands covering frequency ranges from 1-20 Hz and 10-30 Hz. The UAN remained unaffected at the microseism frequency range (< 1Hz) during all three episodes of lockdowns. The sources of energy at this frequency are oceanic activities. Therefore, as expected, it is unrelated to the change in human-related activities.

The three frequency bands covering the microtremor range, e.g., 1-3Hz, 1-10Hz, and 1-20Hz, showed remarkable changes in ambient noise energy changes during the lockdown. The major sources of ambient noise in these frequencies are the cultural activities that were most affected during curfew times. The other frequency which is not affected by these decrees is the very high-frequency band (10-30 Hz).

Figures 3 and 4 show the RMS amplitude of the UAN at a frequency range of 4-14 Hz inferred from the above frequency analysis of ambient noise in the study area. A clear decrease in UAN at this frequency range corresponds well to both imposing and lifting the curfews in the city. This change is even more prominent over median UAN from the 6-16 hours' time window. Such decreasing trends in the UAN energies especially, in metropolitan regions are discussed elsewhere (Diaz et al., 2021; Ojeda and Ruiz, 2021; Pérez-Campos et al., 2021). Figure 4c show the results of the seismic effects of the temporal changes of the mean diurnal amplitudes between 05:00 and 20:00 local time.

A similar approach to highlighting the noise change at a particular frequency range can be seen in other related studies (e.g., Pandey et al., 2020; Poli et al., 2020; Somala, 2020; Yabe et al., 2020; Arroyo-Solórzano et al., 2021; Grecu et al., 2021; Kuponiyi and Kao, 2021; Nimiya et al., 2021; Pérez-Campos et al., 2021; Shen and Zhu, 2021). This is the frequency range where most of the day-to-day human activities occur like walking, traveling and other related cultural activities. Countries that have undergone mobility restriction measures due to COVID-19 pandemics recorded a drop of up to 50% in the amplitude of UAN (Lecocq et al., 2020a).

For the NNA station, we observed a 37% decrease in the amplitude of noise displacement after the start of quarantine. The RMS amplitude as a function of week-days shows the difference in levels during the weekends especially over day hours. During curfew times the daily noise has reduced from > 0.8 nm to < 0.4 nm to weekend levels (Figure 4b).

The variations in the hours of day and days of weeks are also analyzed by calculating ambient noise PSD so that a link between the COVID 19 and noise reduction can be established. The relative change in PSD is calculated at three different frequency ranges (3-5 Hz, 4-14 Hz, 5-10 Hz), particularly affected by the urban activities following an approach adopted after Nimiya et al. (2021). The hourly variations in noise follow a distinct pattern associated with anthropogenic activities (Nimiya et al., 2021). These PSD presentations show the temporal variations in UAN at different hours of the days before, during and after the COVID lockdown (Figure 5). The results are consistent with studies in similar regions and present an acceptable correlation with other information sources such as reports of mobility measured during quarantine. At frequency band 3-5Hz a clear reduction in PSD is seen particularly at 6-9 hours time at the onset of the lockdown in Peru. The possible cause of this reduction in the closure of school and workplaces and related reduction in public transport. The same effects can also be seen at other hours of the day. The same PSD reduction trends are visible in all frequency bands. Similar trends of PSD reduction on other frequency bands are also visible (Figure 5). These variations in noise PSD at all considered frequency bands returned back after the lifting of lockdown restrictions.

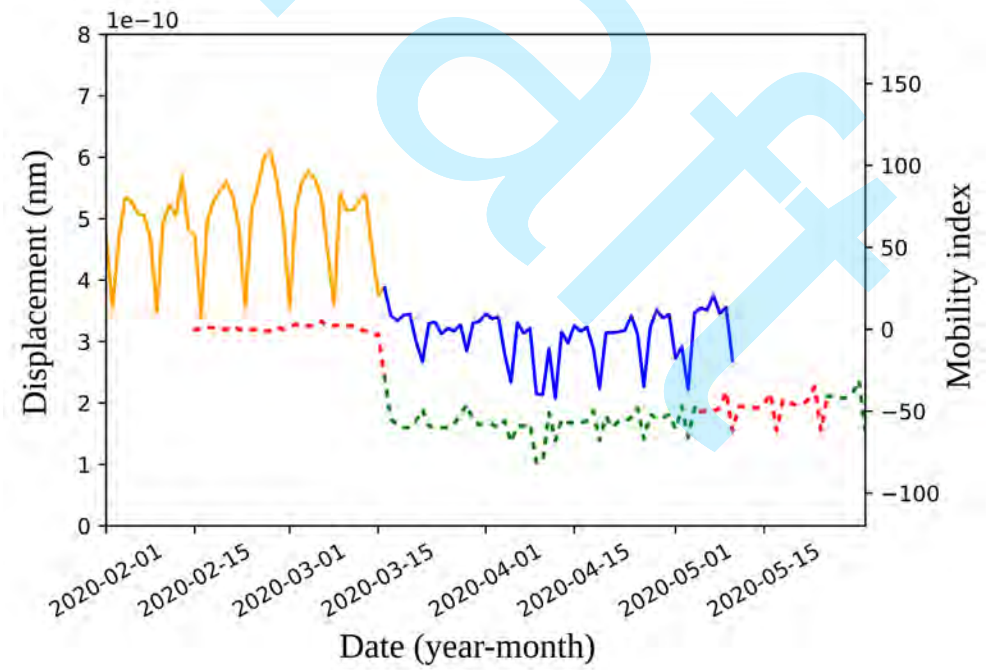

Figure 5. Temporal variations of ambient noise PSD at different frequency bands during different hours of the day. The solid red lines indicate curfew times.

The results show a good correlation with the CPA indicating a point of change at the beginning of the quarantine (03/15/2020) in the time series. In Figure 6, these RMS displacements (solid line) are compared with the Google generated mobility report (dashed line). The change-point presents that both time series have underlying distributions with the same pattern of changing, indicating that human mobility patterns are most probably affecting UAN. These comparisons are conducted at different times of the day when the cultural activities are high. These results are consistent with previous studies; however, they have adopted different ways of comparison (Maciel et al., 2021).

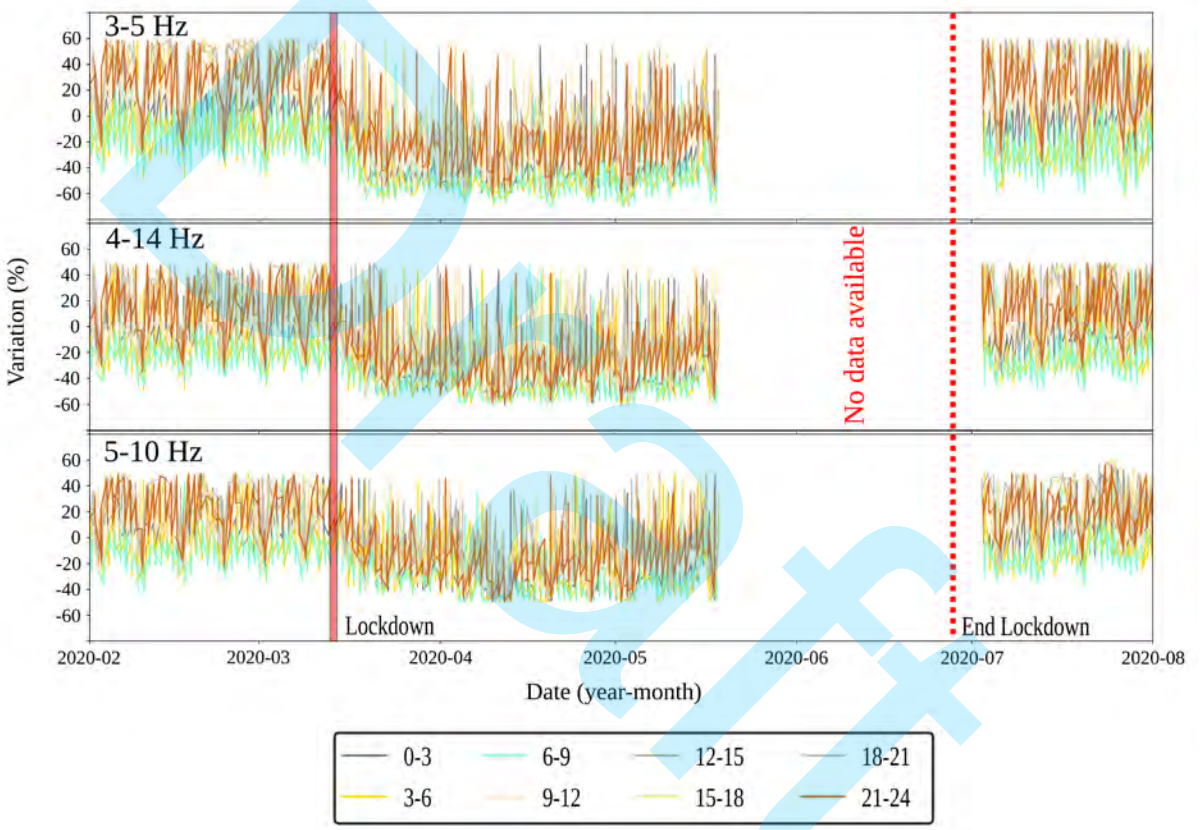

Figure 6. CPA results of noise displacement amplitude in the frequency band from 4 to 14 Hz (solid line) and the Google Mobility Index (dashed line) for the same period. The changing color depicts the results from change-point detection.

Finally, the present study was limited to data availability at a single seismographic station located at one end of the Metropolitan region of Lima, and we believe this can be influence in the absolute estimation of urban environmental noise. However, with the availability of data at multiple locations (array) the further analysis such as attenuation of urban ambient noise with social distancing, its polarization and subsurface tomography could be established.

4 CONCLUSIONS AND RECOMMENDATIONS

The present study was carried out to check the variabilities in urban ambient noise levels considering the time and frequency created by the slowdown in human activities due to COVID-19 lockdowns in Lima, Peru. The following conclusions have been drawn from the analysis:

i Results show a decrease in urban environmental noise by up to 37% in the Metropolitan region of Lima which confirmed the human origin of UAN.

ii At microtremor (>1 Hz), important temporal changes with similar trends and behaviors were observed in the mean diurnal amplitudes between 20:00 and 05:00 (local time); however, at low frequencies (0.1–1, 1–3, and 3–5 Hz) no significant changes were observed.

iii The CPA showed a good correlation between the ambient noise and people's mobility data as both time series show similar trends.

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