Urbanization effect on Hyderabad seismic station

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Seismographs record earthquakes and also record various types of noise, including anthropogenic noise. In the present study, we analyse the influence of the lockdown due to COVID-19 on the ground motion at CSIR-NGRI HYB Seismological Observatory, Hyderabad. We analyse the noise recorded a week before and after the implementation of lockdown by estimating the probability density function of seismic power spectral density and by constructing the daily spectrograms. We find that at low frequency (<1 Hz), where the noise is typically dominated by naturally occurring microseismic noise, a reduction of ~2 dB for secondary microseisms (7–3 s) and at higher frequency (1–10 Hz) a reduction of ~6 dB was observed during the lockdown period. The reduction in higher frequencies corresponding to anthropogenic noise sources led to improving the SNR (signal-to-noise ratio) by a factor of 2 which is the frequency bandwidth of the microearthquakes leading to the identification of microearthquakes with MI around 3 from epicentral distances of 180 km.

Keywords. Seismic noise; probability density function; noise model; anthropogenic noise; spectrograms; lockdown; NHNM; NLNM; microearthquakes.

1. Introduction

Much of our understanding of the Earth’s interior has been gleaned from the recordings of seismic waves of different frequencies. However, noise, caused by other processes including anthropogenic activities, has always been problematic for seismologists since it masks the desired signal. Various filtering and spectral analysis techniques have helped in either getting rid of noise or suppressing it. Interestingly, in recent years, techniques have been developed to use noise to decipher the shallow crustal structure or to characterize the source of noise. Ambient seismic noise is broadly divided into two categories, microseisms (infra low frequency waves) (Longuet-Higgins 1950; Oliver and Ewing 1957; Stutzmann et al. 2000) and earth’s hum (infra gravity waves) (Rlie and Romanowicz 2004; Nishida et al. 2007; Webb 2007). Cultural noise, wind and infrasound pressure variations together are generally the dominant source of noise in the frequency band 1–20 Hz (e.g., Withers et al. 1996; Le Pichon 2004; McNamara and Buland 2004; Marzorati and Bindi 2006; Burtin et al. 2008) which is also the band where most of microearthquakes at local and regional distance appear.

In this paper, we demonstrate how the lockdown implemented after March 22, 2020, led to the reduction in seismic noise, affected the recordings at the Hyderabad (HYB) broadband seismological station located in the CSIR-NGRI campus. We analyze seismograms for the period 15th February, 2020 to 5th April, 2020 for the background noise as...
a function of frequency both pre and during lockdown period. We use different methods to demonstrate and quantify the reduction in seismic noise levels recorded at HYB broadband seismological station during lockdown due to the reduction in anthropogenic noise.

2. Data and processing

The HYB permanent broadband station at NGRI, Hyderabad, India is located at 17.4186°N and 78.5521°E. The station is equipped with a Guralp CMG-3T seismometer with the frequency response from 50 Hz to 120 s, and is coupled to 24-bit Digitizer and GPS (Global Positioning System). The data are recorded at 100 samples per second. The instruments are housed in a double vault thermally insulated room on an underground pier, anchored to the granitic bedrock. We use the seismograms from 15 February, 2020 to 1 March 2020, 15 days before the lockdown and 15 days during the lockdown from 22 March, 2020 to 5 April, 2020. Apart from Hyderabad station, two other stations with similar setup are considered for analysis; one located in Srisailam (SRLM) Kurnool district near to highway road and other at Racherla (RCLA) in Prakasam district placed in an isolated region away from the city.

The probability density function (PDF) of the power spectral density (PSD) of noise is estimated using the method of McNamara and Buland (2004). In this approach, seismograms are analyzed after applying instrument correction for the digitizer and the seismometer gain factor and no filtering is applied to remove earthquakes, spikes, calibration, and mass centering pulses, gaps, etc., which are transients and have low probability value with significantly not impairing the background noise levels.

Seismic noise is stochastic in nature, hence amplitude spectral density (direct Fourier integral) does not converge. Instead, we need to determine the power spectral density \( P(v) \) using Welch’s Method which is the Fourier transform of the autocorrelation function \( \langle f(t) f(t + \omega) \rangle \). The symbol \( \langle \rangle \) indicates averaging over the time \( t \). Depending on whether \( f(t) \) is a displacement \( (d) \), velocity \( (v) \) or acceleration \( (a) \), \( P(v) \) units are \( m^2/Hz \), \( (m/s)^2/Hz \) or \( (m/s^2)^2/Hz \), respectively. In acoustics, the relative seismic signal or noise power \((a^2/a1)^2\) is often expressed in units of dB. For broadband seismometer (velocity meter) the velocity power spectral density in units of dB referred to 1 \((m/s)^2/Hz\), can be written as (Peterson 1993):

\[
P_v [dB] = 10 \log(P_v / 1 \ (m/s)^2/Hz).
\]

All power spectral densities (PSDs) are calculated using a 1-hr time window segment using Welch’s averaging period gram method (Welch 1967) with 50% overlapping. Data were also reduced to zero mean value and a 10% Hanning tapering was applied to get smooth FFTs. The number of samples in the 1-hr time series, the record length, \( T_r = N \Delta t \) (\( \Delta t = 1/fs \) sampling frequency) is chosen such that it is 10 times the longest resolvable period, \( T \). The shortest period, \( T_s \) is 2\( \Delta t \) and the resolvable periods range between 120 s \( \leq T \leq 0.02 \) s. Finally, the PDFs are obtained with 90% confidence intervals by taking average of PSDs in 1/3rd octave bands with center period of the octave as \( T_c \). At every \( T_c \), the probabilities are calculated (Bendat and Piersol1971; Peterson 1993; McNamara and Buland 2004). Figure 1 shows the power spectral densities for pre- and during lockdown period at HYB broad band seismological station for the vertical component (in black) and compared with the standard Peterson curves (in blue) which are used to evaluate the noise at seismic sites, i.e., the new low noise model (NLNM) and new high noise model (NHNM).

Pre- and during lockdown, PDFs are calculated for all stations’ three components, however, we are showing the vertical component observations in figure 1 with mean PDF in 0.01–50 Hz denoted by black line and variations of velocity powers in probability levels with colour bar. In 1–20 Hz band for all the three stations, highest probability power levels range between 15% and 30% before lockdown whilst, for the same period range during lockdown the noise is reduced and the mean PSD is dropped with lower probability levels between 10% and 20%.

Figure 1(a, c, and e) shows that among all the stations in 1–20 Hz band before the lockdown span, the HYB station has a high likelihood of occurrences of noise (in red, 30%) shown in figure 1(a). Interestingly, all stations clearly show two peaks, one with high amplitude at 7–3 s period and the other with lower amplitude at 10–16 s irrespective of lockdown. These are called secondary and primary microseisms or ocean gravity waves, respectively, generated by the mechanism of the atmosphere–ocean–seafloor coupling and their amplitudes depending on the distance from the ocean (Longuet-Higgins 1950; Stutzmann et al. 2000). The pink colour lines represent some temporary signals with less probability levels of less than 2%, these
low-probability transients cannot contaminate the high-probability background noise in PDF curve.

3. Results

3.1 Temporal variation of noise

Figure 2(a, b and c) represents comparison of pre- and post-lockdown mean PDFs at HYB, SRLM and RCLA stations, respectively. The pre-lockdown mean noise PDFs for all the three stations are shown in blue line, post-lockdown mean noise PDFs are in green line and dotted lines represent the NLNM and NHNM (low and high noise models) relative to 1 (m/s)^2/Hz. All the station pre-post lockdown mean PDFs are within the NLNM and NHNM models.

The noise fluctuations in the 0.01–0.1 Hz range are caused by the tilt of the surface-mounted seismometers and/or barometric effects (Given and Fels 1993), and they vary from station to station as
shown in figure 2. These variations are insensitive to lockdown initiation. After lockdown, a slight 2 dB decrease in seismic energy is observed in the 0.14–0.4 Hz band (7–3 s) at HYB station. However, almost all stations exhibit high noise level variations in the infra low frequency band 1–20 Hz, for pre- to post-lockdown as the stations are within the city and anthropogenic noise are linked to traffic turbulence, human activity, buildings, aircrafts, wind movement, exhaust cooling fans, compressors, water-tank and other industrial machineries (Blazier 1981; Backteman et al. 1983a, b; Berghund et al. 1996).

The signal-to-noise ratio (SNR) between pre- and post-lockdown duration is evaluated by taking the ratio of power spectral densities in linear scale (or difference in log scale (dB)) between pre- and post-lockdown duration. The SNR of all stations are compared and shown in figure 2(d) in 0.01–50 Hz range. The HYB site is only 0.7 km from the nearest highway and metro train line and is within the city, SRLM is near to major highway road about 0.5 km distance away from city, whereas RCLA is away from the city and major roads, hence among all RCLA exhibit less noise variation in this band (figure 2(d) in blue colour). In figure 2(d), the green colour line represents SNR at HYB station is almost constant around 6–7 dB in 2–10 Hz band, suggesting more number of close sources of vibration might be the cause of ground motion at these frequencies and a 6-dB drop in seismic energy is due to decrease in cultural noise generated due to various sources due to lockdown initiation.
The SNR at SRLM station (red colour in figure 2(d)) is peaking at 4–6 Hz band. SRLM has highest SNR between pre- and post-lockdown as the vehicles on highway roads are restricted due to lockdown. If we compare figures 1 and 2, SRLM has high noise levels but with less probabilities, whereas HYB has slightly low noise level with high probability of occurrences.

Another way to visualize the effect of lockdown on the noise is by calculating the spectrograms (Diaz et al. 2020). Spectrograms are calculated for 15 days based on averaging 1-hr PSDs using Welch method with 50% overlapping to minimize the variance in PSD. Spectrograms of all three components are shown in figure 3(a, b, c) and a remarkable variation in PSD is noticed above 1 Hz in all the three components after the lockdown on 22 March, 2020 which can be seen as light blue shade. In the microseism band (0.1–1 Hz), larger energy amplitudes (yellow colour) are visible in the entire spectrogram prior to the lockdown in contrast during the lockdown period the energy amplitudes are reduced and further, the horizontal components have lesser energies in comparison to the vertical components.

The main cultural noise variation is seen in the high frequency band (1–10 Hz) at HYB with an average decrease of 6 dB after lockdown in all components as shown in figure 3(a, b, c). The random noise between (2–10 Hz) bands may be due to random sources of vibrations in the crust due to vehicular traffic and human activity (Backteman et al. 1983a, b; Berglund et al. 1996; Diaz et al. 2020). Although the effects from individual sources might be small, cumulatively the background noise becomes significant as they have similar frequency band. Spectral lines in yellow and light blue colours in figure 3(a, b, c) between 10 and 20 Hz could be due to a different constant source near to HYB station.

The frequency band around 18–30 Hz has consistently large amplitudes in the vertical component in comparison to NS and EW components as observed in figure 3 and the sources responsible for the seismic noise could be located within 20–30 m from the station, like traffic rumble, air condition compressors, exhaust fans and other types of machinery. The band at 16 Hz appears as a rough peaky tone generated by the various anthropogenic sources within 100 m distance (Ozyazicioglu et al. 2020).

An earthquake recorded on 24th March, 2020, is clearly seen in red colour (high energy) at low frequency band below 1 Hz in all components, whereas for earthquakes recorded on 18th and 19th March, 2020 before lockdown appears to have relatively less energy because of low noise (clearly differentiated in EW component in figure 3(c) with yellow colour). Since microearthquakes with magnitudes Ml < 3 have corner frequencies in the frequency range 1–10 Hz and also the frequency band of anthropogenic noise and a reduction of noise by 6 dB results in better detection of microearthquakes.

Figure 4 shows the Pulichintala earthquake recorded before the lockdown and during the lockdown at HYB station at ~180 km from the epicentral region. Comparing the Pulichintala earthquakes of similar magnitude, Ml 2.4 recorded prior to the lockdown and during lockdown at HYB, it is clearly evident that due to good signal-to-noise ratio during the lockdown body waves and surface waves are well recorded, whereas before the lockdown period only surface waves are seen. Further, the increase in detection of earthquakes post-lockdown is due to the reduction in the noise.

### 3.2 Daily fluctuations

To analyse the random behaviour of higher frequencies (2–10 Hz) caused mainly due to urban noise, all PSDs are stacked over a frequency band of 2–10 Hz and smoothed with an 8-hr sliding window for 15 days from mid-March. The hourly fluctuations are analyzed for 15 days as shown in figure 5 and it can be noticed that there is a decrease in daily average noise level due to the lockdown. During the 24-hr cycle, the maximum amplitudes are observed around 09–11 hrs UTC (3.30-5.30 PM local time) due to day noise, whilst the minimum amplitude is observed during late night at 18–20 hrs UTC (12.30 AM–2.30 AM local time) as seen from figure 5. The average difference in PSDs between day and night is 5 dB which can be seen from figure 5 before lockdown, whereas after lockdown the day and night noise variation is minimized because of reduced urban noise. This is also an indication that the day noise increases over night by a factor of 2 (6 dB) as shown in figure 5 for frequencies of 2–10 Hz, whilst no variations are observed above 10 Hz diurnally (shown in figure 3). This suggests that the source responsible for this seismic noise is correlated with the possible sources of anthropogenic noise, which is minimized at night and after lockdown.
While no significant day/night variations are usually observed in the microseismic band, a few studies report diurnal variations in the frequency range between 1.0 and 10.0 Hz (Wilson et al. 2002), reflecting the influence of cultural noise (e.g., automobile traffic, industrial sites).

Figure 3. Spectrograms with PSDs shown relative to $10 \times \log_{10}[(\text{m/s})^2/\text{Hz}]$ in colour bar (red with high and dark blue with low PSD) for 15 days from mid-March at HYB. (a) Vertical, (b) NS and (c) EW components. Between 1 and 20 Hz, two spectral lines in black box shown in (a) are common in all components (due to permanent sources <40 m). A red arrow in spectrogram differentiates light blue and dark blue regions on 22 March Sunday local time, first day of lockdown due to offset of cultural noise (shown in red box in (a)). Same is observed as in (b) EW and (c) NS components.
Further, the sharp spikes in Figure 5 during 16, 23 and 30 March 2020 are due to calibration pulses which are generated for every 7 days. The high magnitude spikes on 21 and 25, March 2020 are correlated with earthquakes of magnitudes Ml 2 and Ml 2.4, respectively. Figure 6 reveals large temporal variations of seismic noise for the pre- and during lockdown time with daytime noise between 3 and 15 hrs UTC (8.30–20.30 IST) reduced significantly during lockdown, however, for night-time the noise variations are comparatively low during 18–02 hrs UTC (0.30–7.30 IST).

3.3 RMS ground velocities

The 15 days data from 15 to 31 March, 2020 acquired by the seismometer at HYB, NGRI site...
are analysed at different frequency bands in time domain using band pass filters for vertical component. The filter frequency bands used are 1–3, 2–10, 2–19 and 10–30 Hz to evaluate the maximum seismic energy levels due to microearthquakes and anthropogenic noises in detail. The energy levels at these bands are evaluated using root mean square velocities at 1-min intervals. In figure 7(a, b and c), we notice an interesting drop of seismic velocities after 22 March, 2020 due to COVID-19 lockdown because of reduced human activity in correlation with figures 1, 2 and 3. We also observe that the measured velocity is dominated by a strong day night modulation whose amplitude decreases during night.

3.3.1 The 1–3 Hz frequency band

This band is dominated by human activity and wind movement. In figure 7(a), after lockdown we observe a drop of RMS velocities from 45 (mode of RMS before lockdown) to 20 nm/sec (mode of RMS velocities after lockdown). The RMS velocities during pre-lockdown are twice the post-lockdown velocities, which justify the SNR increase in 1–3 Hz band in figure 2(d) over 5 dB. The higher noise

Figure 6. Comparison of two 1-d long vertical displacement in (a) and velocity in (b) seismograms recorded at HYB. A full day before lockdown (17 March 2020, IST) and after lockdown (28 March 2020, IST) are represented in black and gray, respectively. The data are presented in UTC times on x-axes. On 17/3/2020 (IST), the level of background noise is high during the day, and relatively low in night probably due to cultural noise. On 28/3/2020 (IST), the background day noise level is lower by a factor of two compared to 17/3/2020, despite the fluctuations in the day. Whereas no variation in the night due to lockdown.
Figure 7. Time series of vertical component RMS noise velocities in (a) 1–3 Hz, (b) 2–10 Hz, and (c) 2–19 Hz band respectively taken from HYB station in NGRI. The duration of the plot is 15 days in the month of March 2020. Each point in the plot represents RMS velocity calculated for 1 min duration of time series signal. We observe a drop in RMS velocities after 22 March, 2020.
levels in the day-time are observed before lockdown between 60 and 200 nm/sec, whereas after lockdown decreased frequency of occurrences of velocity variations observed in this range due to reduced human activity.

3.3.2 The 2–10 Hz frequency band

This frequency band shows the day night modulation associated with human activity, but at a slightly higher level than that was seen in the 1–3 Hz band. There is much larger variation between the velocities measured from pre- to post-lockdowns nearly equal to 85 and 30 nm/sec, respectively (6.5 dB increase in SNR in 2–10 Hz band, figure 2(d)). It suggests that some local source of vibration stopped due to lockdown. In this band we notice low velocity variations in pre-lockdown duration 15–21 March on 15th which is Sunday. In post-lockdown period between 22 and 31 March significant lowering of velocities observed on 22 and 25 March which are public holidays (Sunday and Ugadi) and NGRI was completely closed, whereas NGRI Observatory was partially open during other days in lockdown. The overall reduction in the slab velocities in 1–3 and 2–10 Hz bands is due to shut down of traffic noise on the national highway road close to the station (700 m).

3.3.3 The 2–19 Hz frequency band

This band of frequency variations is shown in figure 7(c). The RMS velocities measured over 2–19 and 10–30 Hz slabs are similar because no spectral variations observed above 20 Hz (figure 3a). The unique pattern observed in figure 7(c) suggests local source of vibration of compressor ON-OFF noise near to the station exciting the slab. This is also noticed in figure 3(a) spectrogram by a spectral line highlighted in black box representing a permanent source.

4. Conclusions

We assessed the effect of lockdown enforced by the global COVID-19 spread on the seismic noise of HYB broadband seismological station by analyzing composite power spectra characteristic of ambient ground noise in the frequency range of 0.01–50 Hz during a period of reduced anthropogenic noise (15–31 March 2020) due to lockdown. Sources of anthropogenic sources were detected using spectrograms. We observe an overall drop of 6 dB in PDFs relative to \[10 \times \log_{10}\left(\frac{(m/s)^2}{Hz}\right)\] due to lockdown in the octave bands >1 Hz, thereby increasing the SNR by a factor of 2, which has actually led to better detection of micro-earthquakes (MI < 3). Diurnal variations are observed in the band of 2–10 Hz and a variation of 5 dB is noted during pre-lockdown period, whereas during lockdown these variations were reduced, reflecting a reduction in the anthropogenic noise levels. Between 1 and 30 Hz, the dominant noise sources are due to human activity in the vicinity of the instruments. These variations are observed using 15 days’ time series RMS velocities at various frequency bands. Although we are all struggling to cope with the threat of COVID-19 and with the resulting lockdown, the lockdown has provided an opportunity to calibrate the seismic noise at HYB seismological station and has allowed us to quantify the variations in the seismic noise in the pre- and during lockdown periods.

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Author statement

SSP: Conceptualization, methodology, data processing; DS: Methodology, supervision, validation, reviewing and editing; RV: Data Collection, methodology, data curation and station maintenance; VKG: Validation, reviewing and editing. All authors read and approved the manuscript.

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