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Appraisal of seismic noise scenario at national seismological network of India in COVID-19 lockdown situation

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ABSTRACT

We evaluated seismic background noise at national network in India using PSD, Fourier spectra, Spectrogram, and HVSR approach, before and during the nationwide lockdown declared due to COVID-19 pandemic. The analyses were performed to understand characteristics of noise wave-field in such unprecedented situation and its effect on site response at the station. SBN in long period (> 20 s), primary microseism band (10–20 s) and secondary microseisms (1–10 s) performed well and the noise levels found within the new LNM and HNM. However, in short period (< 1 s) the variation in SBN performance found significant before and during the lockdown. We observed that the SBN at each site in short period (< 1 s) is found to be about 10–12 dB noisier in the time segment prior to the lockdown. The HVSR analysis of SBN at recording sites clearly indicates that the predominant frequency for the entire region remains stable and independent of seismic noise generated before or during lockdown. A substantial variation in amplification factor, however, observed in either situation. Most of the stations across the country experienced diminished cultural noise subsequent to declaration of lockdown on 25 March 2020. Such drastic decrease in cultural noise significantly enhanced the performance of noisy stations, and the best recording stations picked the seismic phases originated from micro to small earthquakes. We suggest installation of seismometers at some depth below the surface, particularly at disturbed sites, may substantially reduce short period noise in earthquake recording.

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Seismic noise; broadband seismograph; network; earthquake; lockdown

Introduction

The protective self-quarantine and lockdown measures are being observed across the world over for the past few months to contain the spread of deadly novel COVID-19 virus causing a substantial drop in Seismic Background Noise (SBN), which is also known as Ambient Seismic Noise. The COVID-19 is a novel coronavirus SARS-CoV-2 disease,

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which was identified in December 2019 at Wuhan of China (Andersen et al. 2020). The virus spread the world over in very short span of time that caused illness ranging from the common cold to more severe diseases and lead to many deaths. By mid-March 2020, the World Health Organization (WHO) reported more than 40% confirmed cases globally and announced the COVID-19 outbreak as a pandemic. In such a crisis, a country like India with the population more than a billion declared complete lockdown commenced from 25 March 2020. Due to this lockdown, all public transportation, shopping malls, movie theatres, schools and major industries except the essential services, were temporarily suspended throughout the country. Buses, railways, ferry services and even flights were also halted to reduce large assembly to contain the spread of the disease.

We believe that the prevailing lockdown might have reduced the SBN significantly due to sudden pause of countrywide man-made activities. As a result, micro (M1.3, M1.7 and M2.0) to small (M 2.7 and M3.5) earthquakes could be detected accurately at seismic stations (Pandey et al. 2020; Singh 2020). Amidst all the chaos, the planet Earth appears to have got some time to rejuvenate itself. Usually, SBN is an undesirable component in earthquake records at any seismic station, and is observed like a persistent ground vibration. In addition to continuous movement of the lithospheric plates under the forcing due to mantle currents, the day-to-day generated SBN such as small to large scale meteorological disturbances and man-made activities (e.g., road and rail transports, constructions, heavy machinery and land drills etc.) also apply considerable stress on the Earth's crust. Such man-made activities and seismic coupling due to small scale meteorological disturbance generate short period noise (Li et al. 1984; Peterson 1993; Withers et al. 1996; Young et al. 1996). However, long period seismic noise may be attributed to large scale meteorological phenomenon like monsoon, storms and seasonal variation in weather parameters. McNamara and Buland (2004) argued that the seismic stations installed in urban agglomerations in the United States showed higher noise levels at short period and it was attributed to local geographical variations. We emphasize that these noise sources are quite useful for studying the subsurface structures of the Earth's crust.

Leon (2001), while studying the Rio Grande RISTRA (Rift Seismic Transect) array of broadband seismic stations (BBSs) observed strong variations in SBN for shorter periods (0.1–1.0 s) and longer periods (> 30 s) at different stations. The least amount of variation observed in 0.07–0.2 Hz frequency range (i.e., 5–14 s period), which contains the microseism generated due to storm waves at sea. It was also observed that the sensors placed at loose and unconsolidated filled material, exposed to high amount of cultural activity, recorded higher than the average noise levels in short period. The vehicular traffic raised the SBN in frequency range 0.8–5.0 Hz (0.2–1.25 s), but no distinct peak could be associated with traffic movements (Powell 1992). However, in the periods > 0.25 s, a significant section of noise was produced by surface waves. Wilson (2002) also successfully demonstrated using noise data from temporary seismic stations in South-western United States that a typical noise level for broadband stations were controlled by the local site conditions in long period (> 15 s).

In the wake of COVID-19 pandemic, to contain spread of the virus, the entire country was called lockdown since 25 March 2020 limiting movement of more than 1.3 billion people of India. Such huge decision imposed sudden restriction on

transport, vehicles, trains, metro, aeroplanes and heavy to light machines etc. leading to instantaneous reduction of SBN. This situation provided an opportunity, on the other hand, to explore possible impact of such drastic change on ambient seismic noise at National Seismological Network (NSN) spread over various parts of India. Ambient seismic noise monitoring at a site may help understanding utility of waveforms recorded at seismic stations (Given 1990; Li et al. 1994). A waveform is also found affected by intrinsic noise of the recording system that may be associated with the SBN (Rodgers et al. 1987; Powell 1992). Although some high frequency spikes are evident either due to unknown vibrations of the equipment or intrinsic sensor noise, the system noise levels are typically found well below the one generated by man-made sources. However, the system noise could be a matter of concern at very quiet sites.

Stutzmann et al. (2000) suggested appropriate characterization of SBN is a primary step in minimizing the noise level of seismic data. A good site for seismic stations requires low SBN, which depends upon to what extent we can minimize various noises (Young et al. 1996). In the present study, an attempt has been made to analyse the ambient seismic noise recorded at 115 Broadband Seismograph (BBS) stations under NSN, maintained by National Centre for Seismology (NCS), to estimate changes in the Earth's seismic noise and variation amid the COVID-19 lockdown, and further to assess performance of the seismic stations (Figures 1a and 1b). Here, we particularly focus on understanding characteristics of the seismic noise before and during the prevailing lockdown situation, based on analyses of power spectral density (PSD), Fourier Spectra, Spectrogram and Horizontal-to-Vertical Spectral Ratio (HVSr).

Data analysis and methodology

The seismological data from the entire national network, including those operated by other agencies funded by the Ministry of Earth Sciences (MoES), are compiled, processed, analysed and archived systematically in DC of the NCS in standard SEED format, which could be retrieved successfully as and when required. The DC is equipped with data acquisition modules, SEEDLINK server for real-time data exchange, data storage, networking and data access infrastructure with regional centres, offline data exchange and information management. All the data collected at New Delhi data Hub is mirrored at Hyderabad data Hub to ensure the data availability in case something goes wrong at either of the locations. All the seismic stations of the national network of India, equipped with tri-axial broadband velocity sensors with 120 s period coupled with 24 bit DM-24 digitiser, are operating at sampling intervals of either 40 or 100 samples per second (sps). As the sampling rates at some stations are 40 sps, we analysed data up to 20 Hz. The longest periods recorded in waveform data found limited to about 100 s. Data from the seismic stations received to Central Receiving Station (CRS) through very small aperture terminal (VSAT). At seismic stations located in loose soil areas, the upper top soil cover removed up to 1.5–4.5 m and a concrete pier constructed for placing the sensor and hence minimized the soil effect. Out of 115 seismic stations, many are located in remote places while some are close

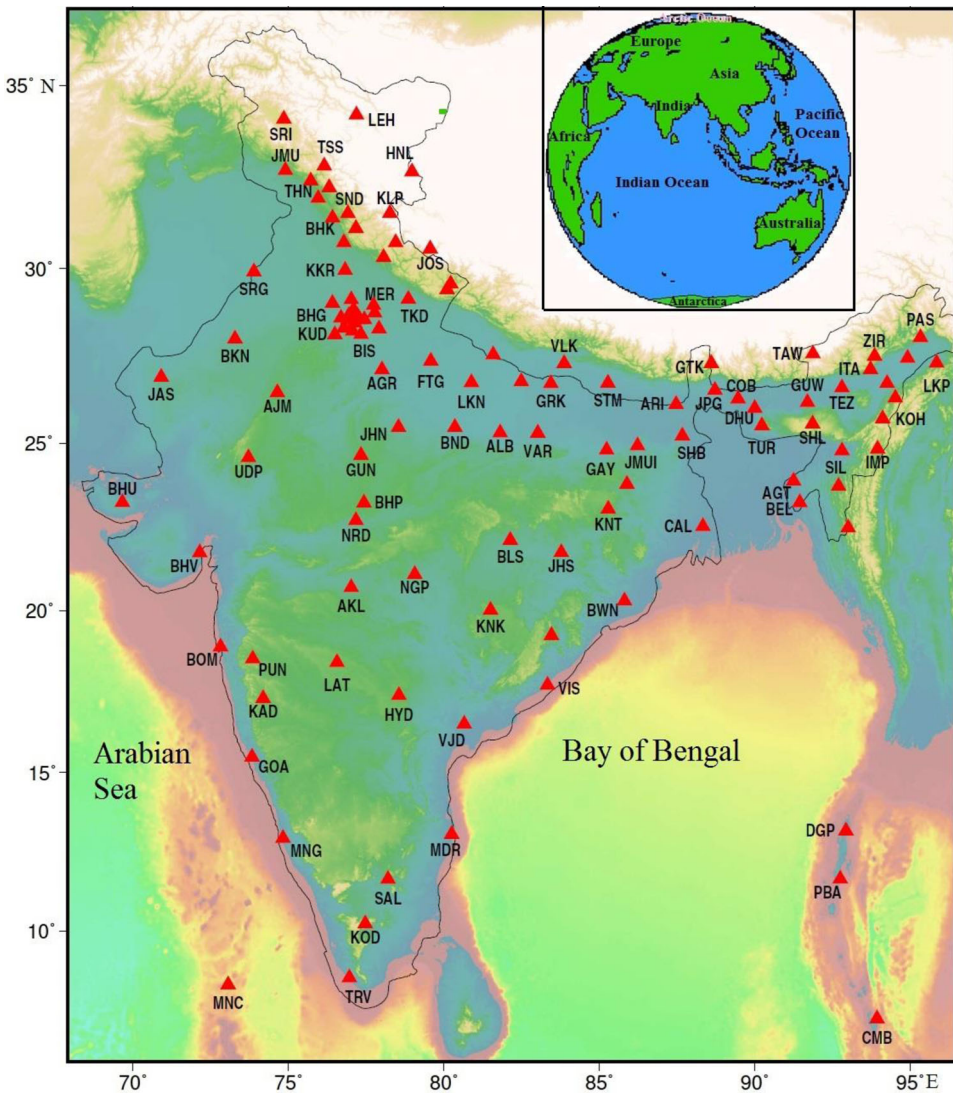


Figure 1 a. The map showing the location of seismic stations of the National network maintained by NCS. The Network consists of 115 broadband seismic stations. Inset: the location of study region in Global map.

to the populated urban agglomeration making them prone to man-made seismic noise (Figure 1b).

Power spectral density

The power spectral density (PSD) approach employed for quantitative assessment of seismic background noise as power (energy) distribution with frequency. PSD is measure of signal strength as a function of frequency which is used to understand the variations of SBN in short and long period spectrum at different time intervals. It is typically used to characterize broadband random variables. We adopted the

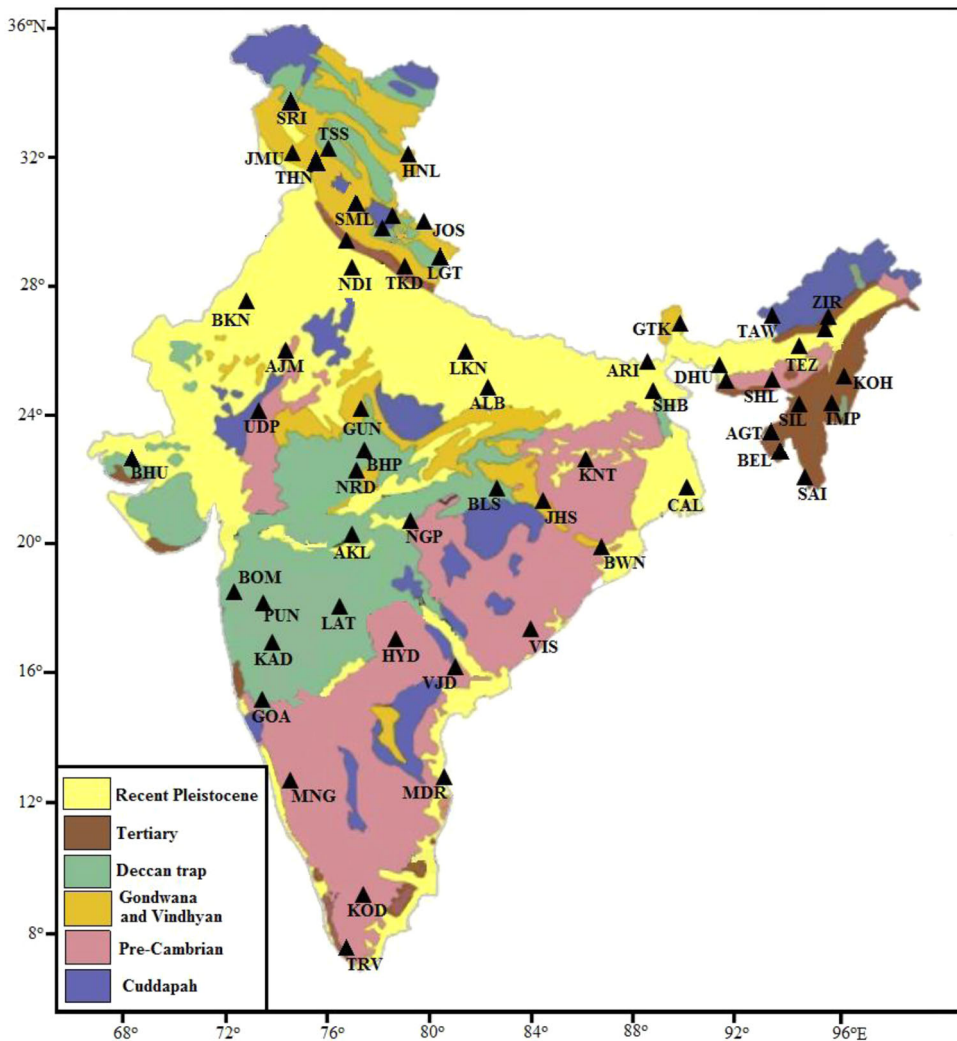


Figure 1 b. Location of seismic stations superimposed over different geological formations (modified after GSI), which are used in the present study. Black triangle shows the location of seismic stations with station code. Source: Geological Society of India, <http://bhukosh.gsi.gov.in/Bhukosh/Public>, Geological Atlas map

formulation proposed by McNamara and Buland (2004) for PSD analysis of SBN at 115 BBS stations across the country, before and during lockdown situations. However, we presented the results for representative 20 BBS stations, considering different geological formations as well as urban and remote areas (Figure 2).

In this study, continuous ground motion data stream of seven days pre and post 25 March 2020, that is the day of declaration of nationwide lockdown due to COVID-19 pandemic, considered for the analysis. The data was selected in a way that the noise sections remain free from local and teleseismic earthquakes, mass centring pulse, calibration pulse and other disturbances. The Rayleigh and Love surface waves in the range of periods from 5 to 120 s are generally dominant in the seismic noise. At higher frequencies body waves make a significant contribution to seismic

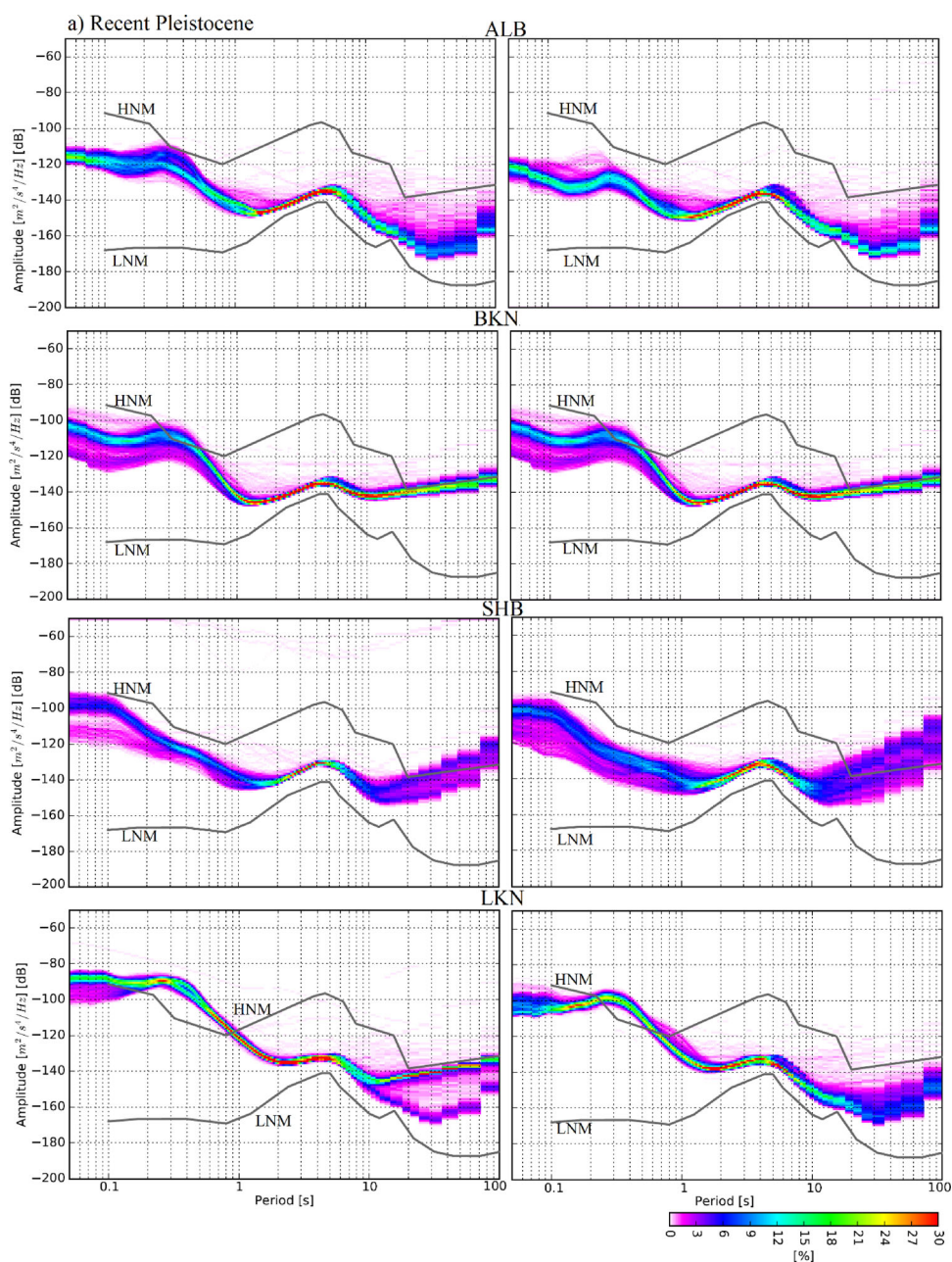


Figure 2. Power Spectral density of the vertical component for the broadband stations of the NCS seismic network before (Left Panel) and during (Right Panel) lockdown. PSDs from the vertical component are shown in decibels (dB) relative to the ground acceleration. Reduction of ambient noise < 1 s is obvious in PSDs; which is higher before the lockdown. The estimated PSDs are compared with the new high noise model (HNM) and low noise model (LNM) as proposed by Peterson (1993).

noise (e.g., Roux et al. 2005; Koper et al. 2010; Landes et al. 2010; Wang et al. 2010). Various researchers have also observed short period noise well recorded on vertical component, and long period noise prominent on horizontal components of the

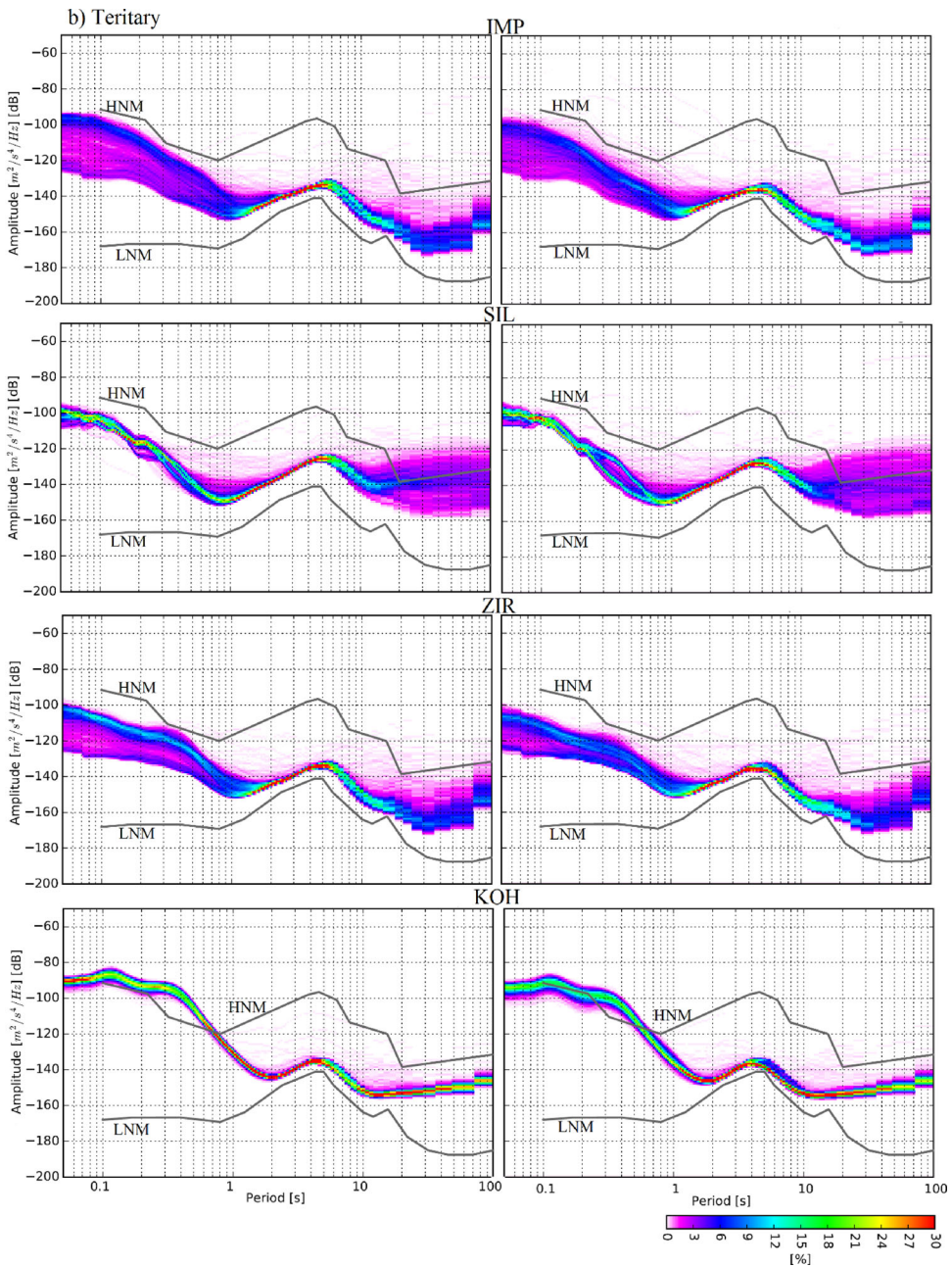


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seismic records (Webb 2002; Kumar et al. 2012; Jana et al. 2017). De Angelis (2008), however, argued that the horizontal components are noisier than the vertical components due to its sensitivity to the tilts of the seismometers, as the gravity effect is coupled to the horizontal components only. Consequently, in the present study, we considered vertical component of ambient noise wave-field in the analysis to understand the influence of COVID-19 lockdown situation. A 30 minutes time window

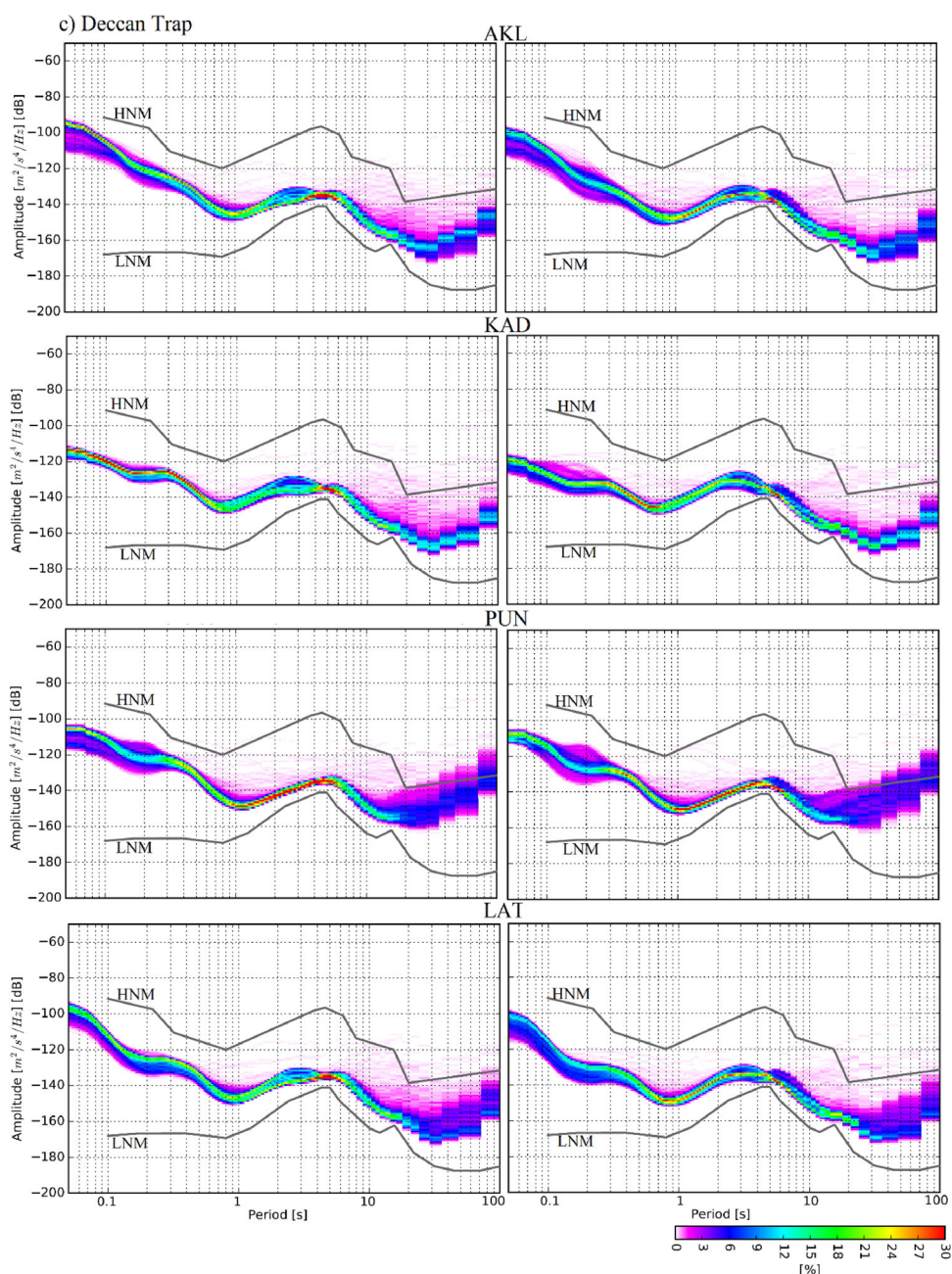


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used for cutting noise samples from homogeneous sections of the ambient noise wave-fields. About 200 samples from each segment of 7 days period (i.e., before and during lockdown) analysed for estimating a single average noise spectrum at each site. We also analysed the waveforms recorded in different time periods such as a week and two weeks separately for PSD and compared. The results are depicted identical in terms of values and patterns. The noise spectra normally consist of signals in

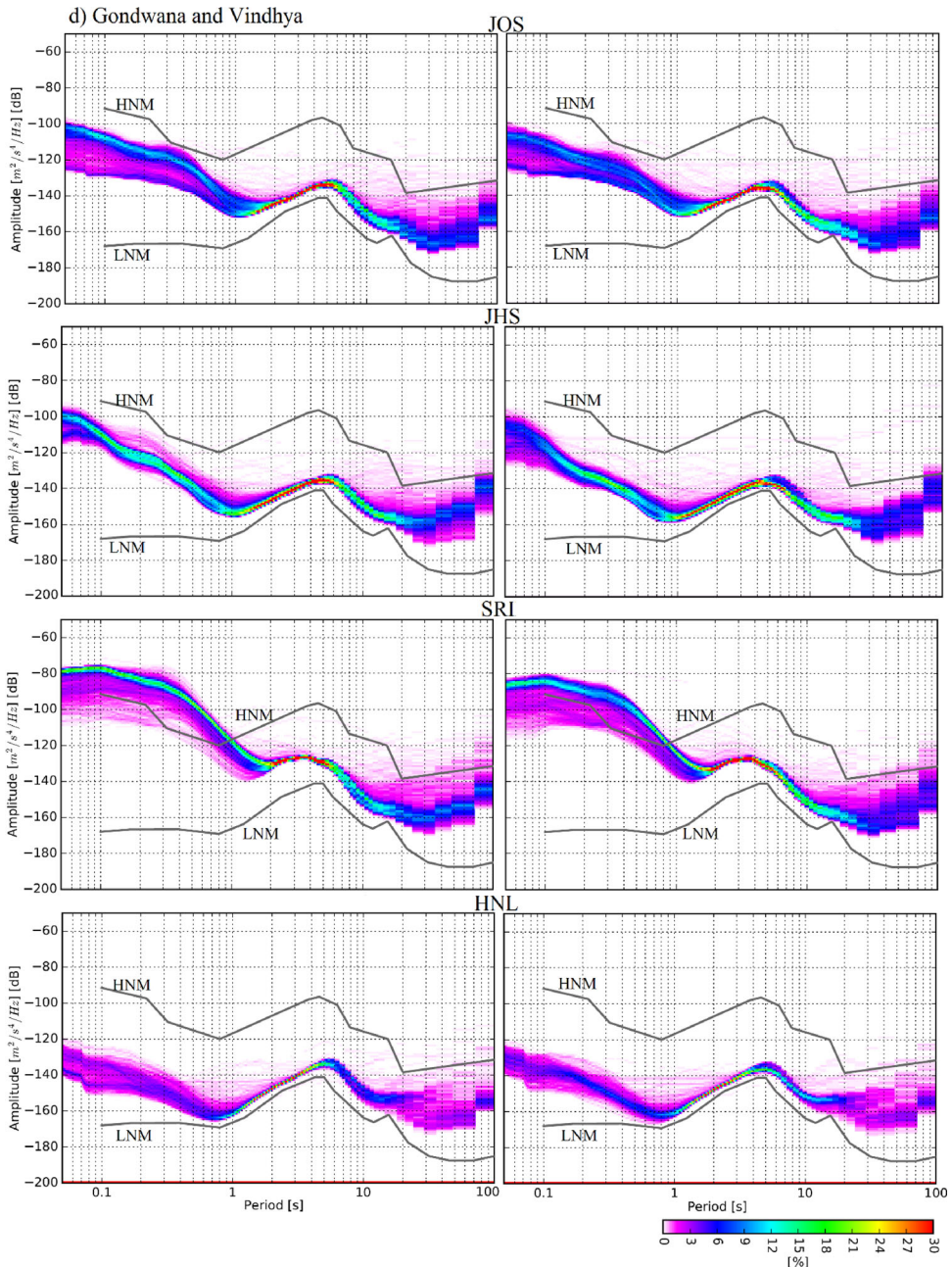


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three separate periods, namely, (0.1–1.0 s) short period, (2–20 s) microseism and (20–900 s) long period (McNamara et al. 2009). However, Yang and Ritzwoller (2008) referred ambient seismic noise in the short-period band (<20 s) as microseisms. We mention that the present study is primarily focused in short period range.

The PSD of SBN recorded over the national network estimated using PASCAL Quick Look Xtended (PQLX) package (McNamara and Boaz 2005). Estimated PSD

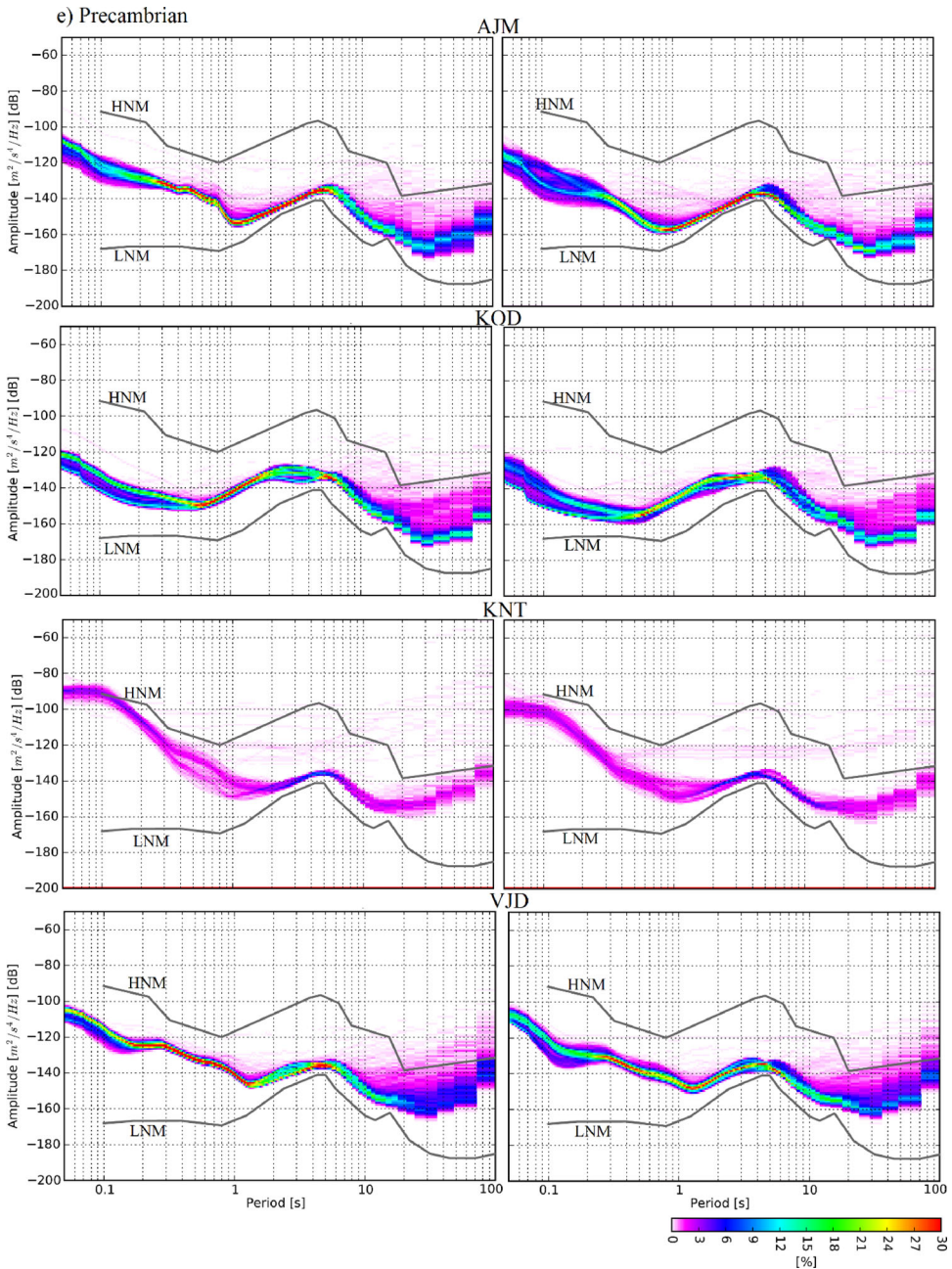


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contains a set of standard reference curves of new Low Noise Model (LNM) and High Noise Model (HNM), which indicate the upper and lower limits of a cumulative compilation of ground acceleration power spectral density (Figure 2). We determined noise power density acceleration spectrum that is commonly known as noise spectrum and is measured in dB (i.e., referred to $(1 \text{ (m/s}^2)^2/\text{Hz})$). The Peterson (1993) models used to determine the strength of seismic noise energy, which characterize



Figure 3. Histograms at various periods (10 s, 5 s, 3 s, 1 s, 0.5 s and 0.1 s) show variations in seismic noise with reference to the new LNM at different seismic stations before and during lockdown.

the sites. We analysed the PSD for each station in period ranges from 0.05 s to 100 s (Figure 2). Further, deviation of amplitude with reference to new LNM were also calculated for these stations and presented as histogram at various periods (10 s, 5 s, 3 s, 1 s, 0.5 s and 0.1 s) before and during the lockdown (Figure 3). We presented the PSDs in periods to compare with the standard new low and high noise models (LNM and HNM) proposed by Peterson (1993), which are considered to be accepted limits of seismic noise. However, the Fourier spectra and the H/V response spectra in the next section are normally produced in frequency domain for better representation of the shape.

Fourier spectra

We applied Fourier Transform technique to understand the site conditions and characterize the response at 10 representative BBS stations (AGT, AJM, BOM, CAL, KOD, MNG, TAW, TEZ, TSS and ZIR), which located in different geological formations (Figure 1b). The Fourier transform decomposes continuous and discrete signals into respective frequency spectrum. The waveforms were selected from 24 hours continuous ground motion records, as shown in Figure 4. The figure shows Z-component ground motion time series recorded at BBS stations; however, the analysis has been performed for all the three components (N-S, E-W and Z). The steps involved in performing Fourier transform on raw data include, (i) subdivision of data into

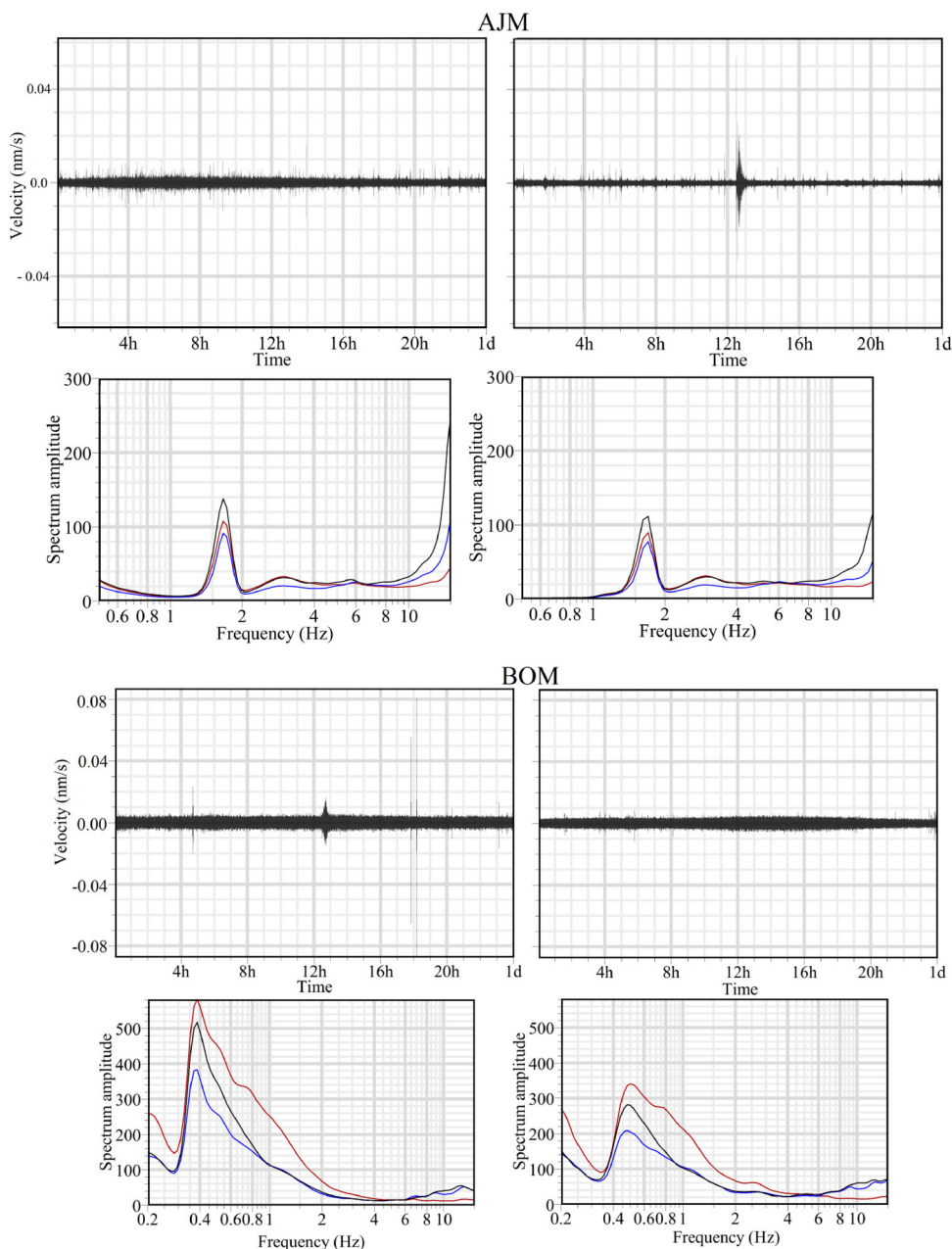


Figure 4. Ground motion time series of Z-component (upper panel) and corresponding Fourier Spectra (lower panel) computed for BBS seismic stations of NCS Network before (left panel) and during (right panel) lockdown. The black, brown and blue colours represent three components of record i.e., North-South (N-S), East-West (E-W), and Vertical (Z), respectively.

smaller windows of time length 50 – 60 s each with 10% overlap, (ii) each window is 5% cosine tapered and transformed into Fourier domain, and (iii) each spectrum smoothed prior to the calculation of spectrum using Konno and Ohmachi (1998) technique for a bandwidth coefficient 40, as the raw signal contained unusual spikes

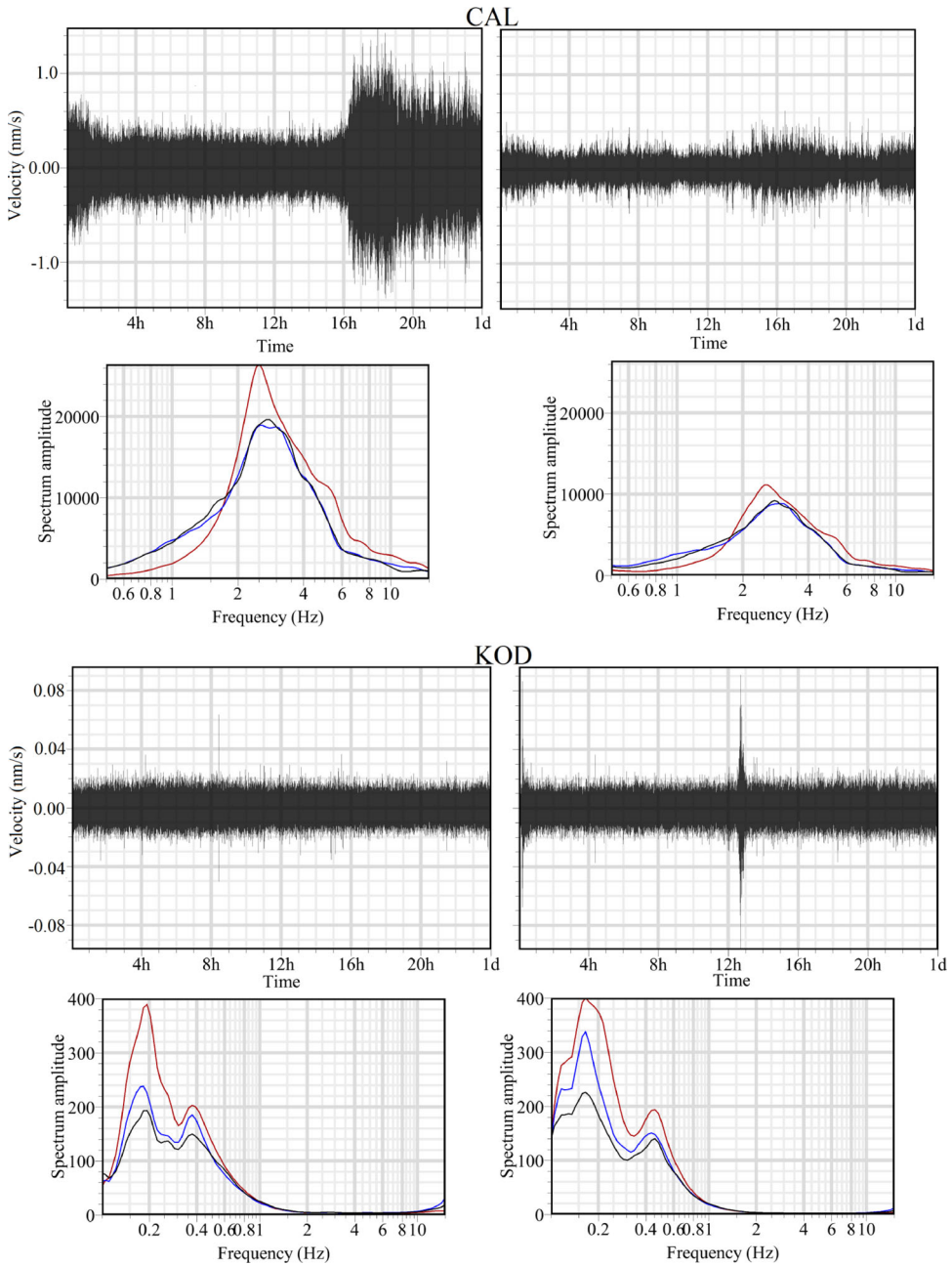


Figure 4. Continued

(Singh et al. 2019). Accordingly, the Fourier spectrums for three components are shown in Figure 4.

Spectrogram

We analysed spectrograms of seismic noise recorded at seven stations (BOM, DDI, VIS, HYD, MDR, CAL and GOA) that were located in urban areas, and they cover

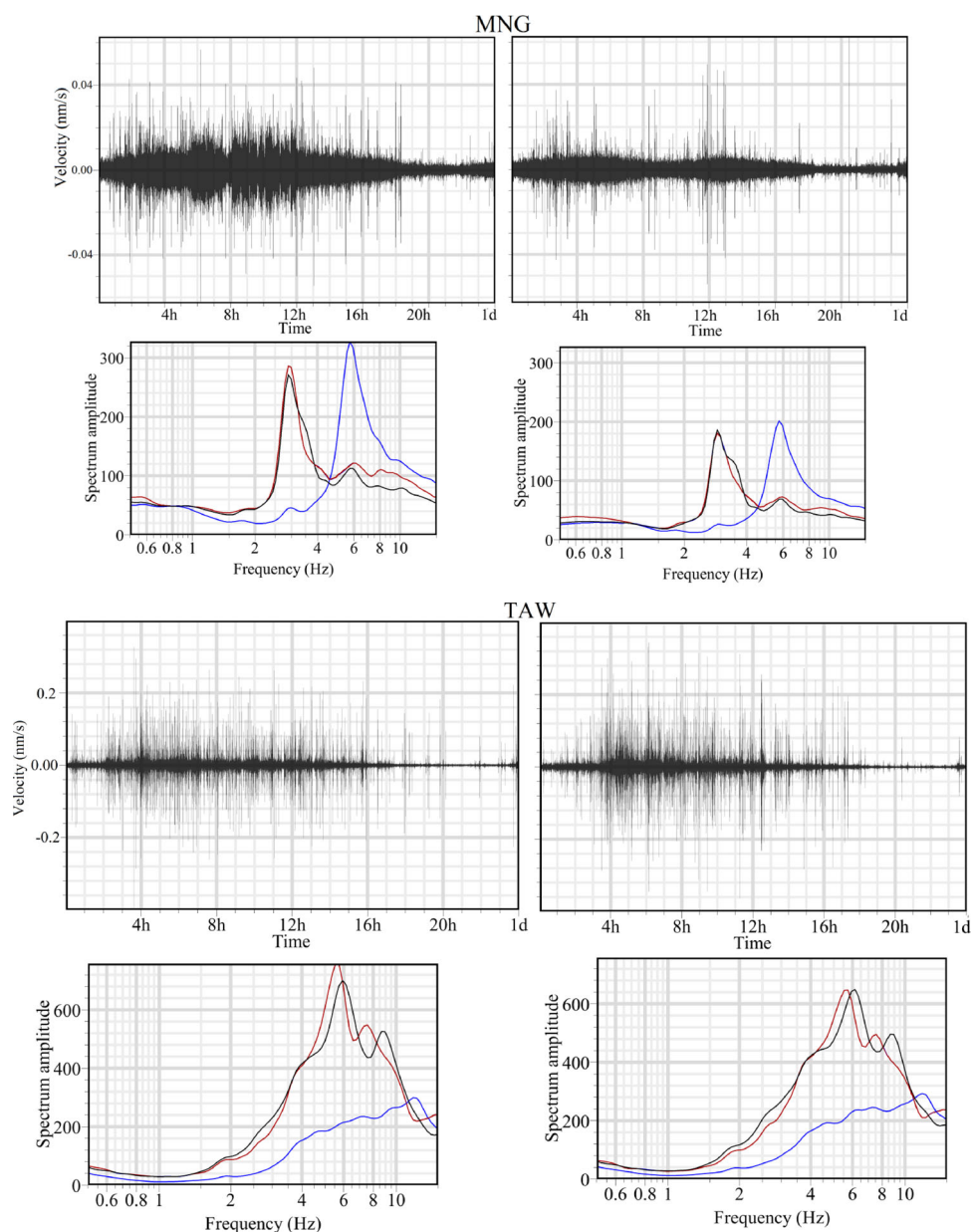


Figure 4. Continued

length and breadth of the Indian subcontinent (Figure 5). We estimated spectrograms by performing Fourier transform on 60 s segments of continuous signal, with 20% overlap between subsequent segments, all segments are then averaged. The spectra were calculated from a squared modulus of the resulting average Fourier transform using Power spectral density (PSD). We selected PSD as it improves resolution and could not produce artefacts in the spectrum due to leakage of energy between different frequency ranges. We mention that the resolution of estimated spectrogram depends on the size of time window.

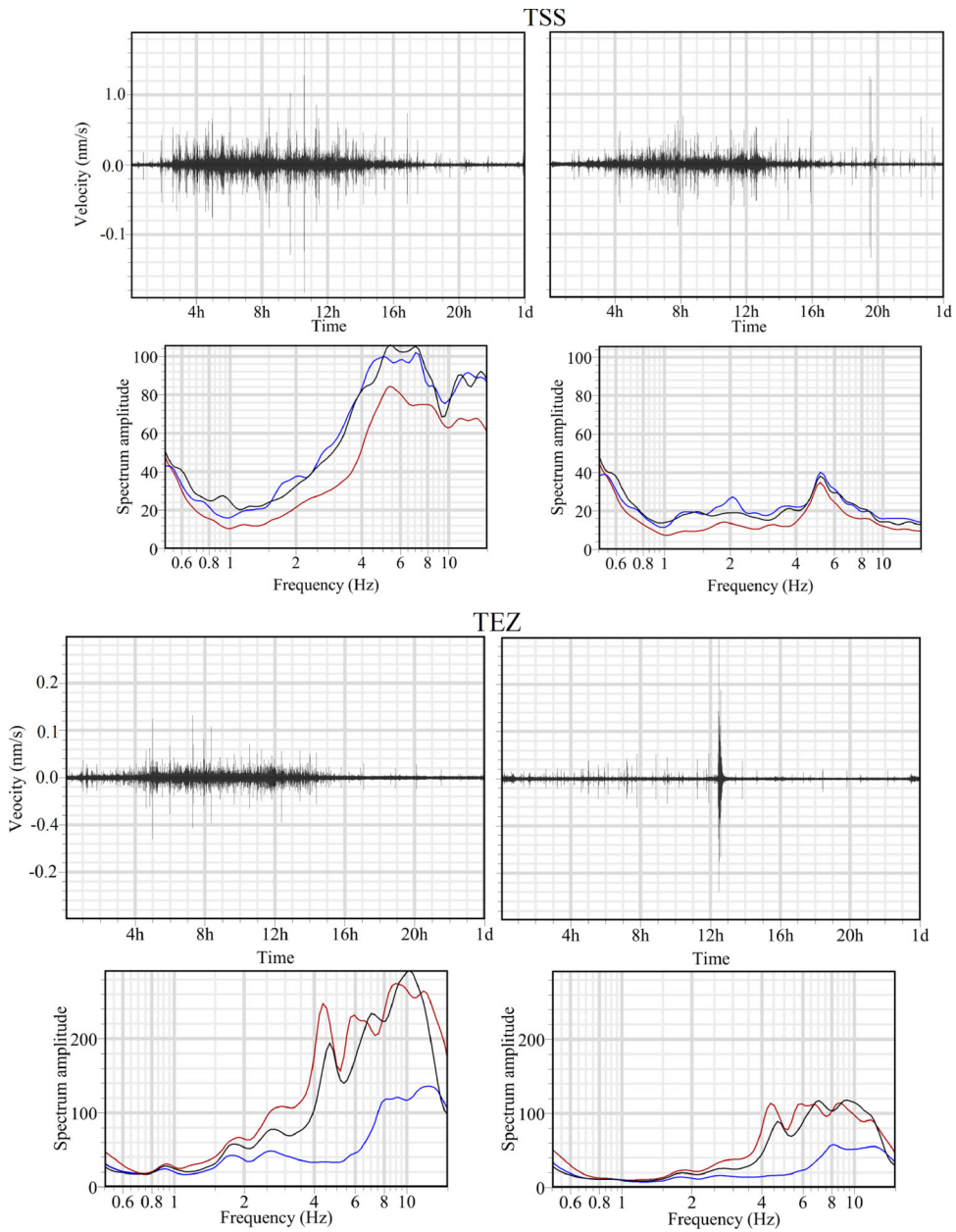


Figure 4. Continued

Horizontal-to-vertical spectral ratio

Continuous record of ambient-noise data at National network offered an opportunity to investigate the nature of HVSR before and during lockdown, which indicates the local site conditions. A quantitative and qualitative indicator of the local site conditions is generally expressed by the predominant frequency and amplification factor. These parameters depend on physical properties of soil at a particular site and depth to the bedrock, which characterize the site for seismic hazard assessment. In the

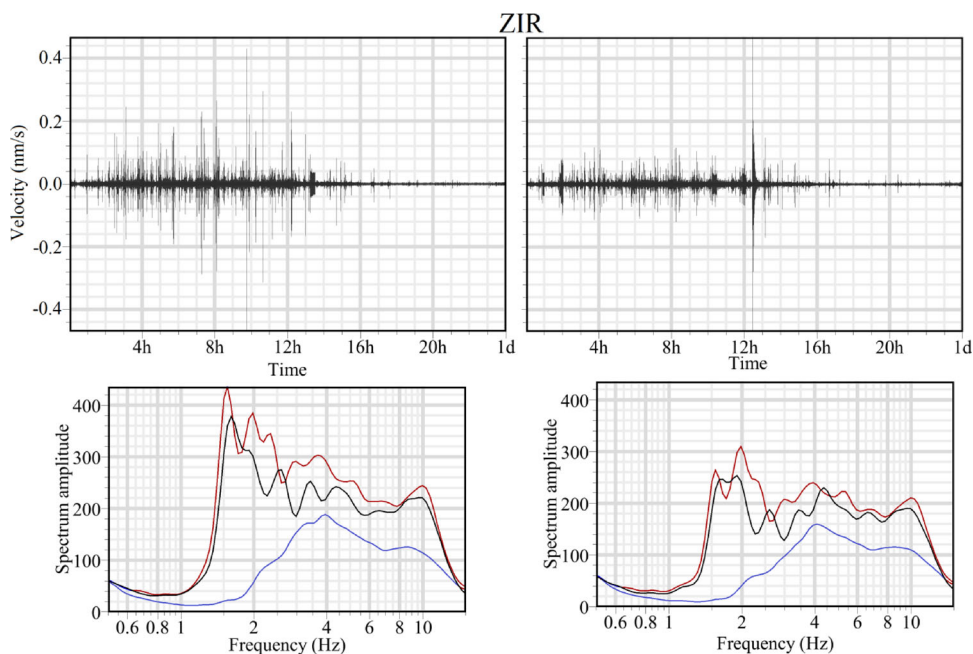


Figure 4. Continued

present study, we used Nakamura (1989) technique to estimate transfer function of 23 representative BBS stations (TSS, THN, MER, NPL, BHG, ALB, VLK, CAL, TAW, TEZ, ZIR, AGT, AJM, NRD, AKL, VIS, MNG, ARI, TRV, UDP, TKD, UJW, and NRD) in terms of HVSR of the time series recorded by three-component seismic stations. The ambient noise data from representative sites analysed for HVSR before and during the lockdown (Figure 6). For accurate estimation of HVSR, we considered 24 hours continuous data for each station. Details of predominant frequencies and amplification factors at each station listed in Table 1. The standard deviations in the HVSR resonant frequencies deduced directly from the curves were found to be ± 1 in all the cases

Results and discussion

Analysis of SBN record is an established robust technique for checking the noise characteristics of a particular seismic station, and compares the level in respect of the global standards. It is originated by numerous transient and permanent sources in different specified time periods. The quantification of such noise makes it possible to appraise the performance of seismic network. We analysed seismic noise using different approach to understand performance of BBS stations before and during lockdown (Figures 2–6). Significant variations in PSD for both the situations, before and during lockdown, found mainly at short period < 1 s, which may be generated due to local wind and man-made activities. We observed a clear peak at about 5 s (0.2 Hz) (Figure 2), which originates globally on the Earth due to interaction between oceanic waves and coastal region (Longuet-Higgins 1950; Friedrich et al. 1998). The SBN at long

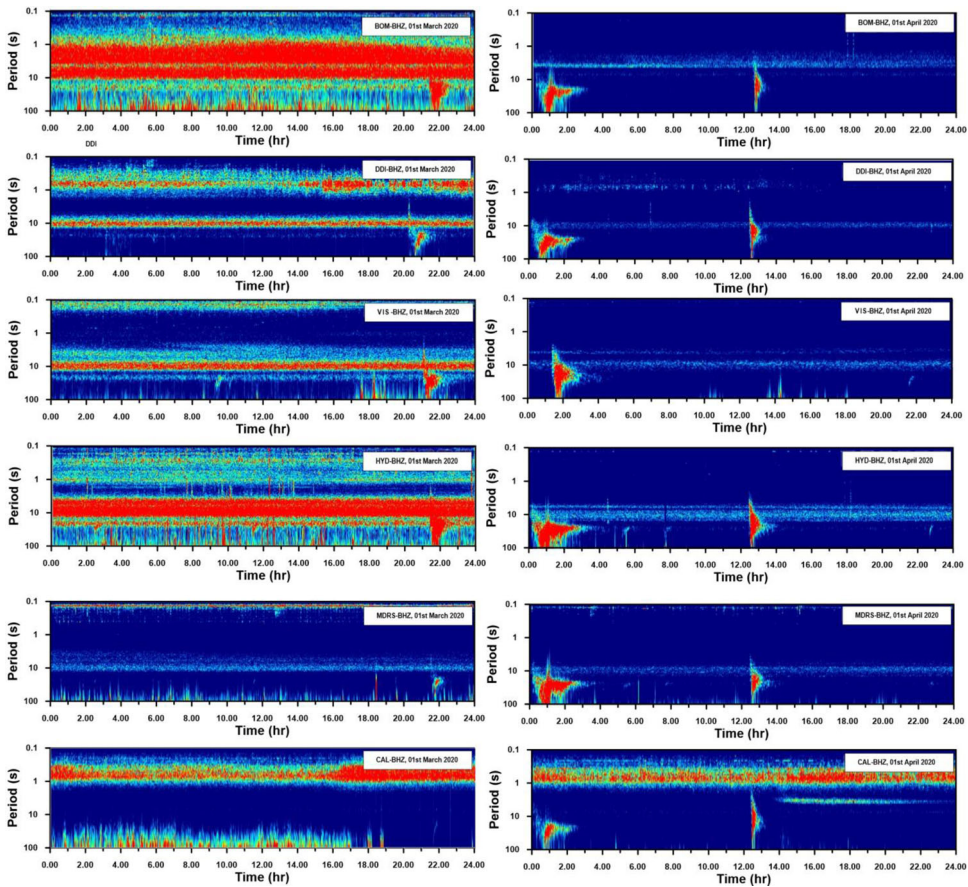


Figure 5. Time frequency analysis of vertical-component seismogram recorded before lockdown (Left Panel) and during lockdown (right panel) at BBS stations of NCS network. Spectrogram panel shows maximum energy variations at period < 1 s, which are generated mainly by man-made activities.

periods (10–100 s) observed within the new LNM and HNM for all the stations with no significant changes in signal before and during lockdown.

We found that the performance of all the stations are significantly different at bands of short period (< 1.0) in noise levels and is more influenced by man-made activities or local scale meteorological disturbances (Powell 1992; Stutzmann et al. 2000). Most of them showed PSD level ranging 100–120 dB at period ≤ 0.1 s. The SBN levels are higher at seismic stations located in the urban areas (e.g., ALB, LKN, AJM, CAL, KOH, TRV and SRI) as compare to remote areas (ZIR, HNL, BHU, JOS and TSS) (Figures 2 and 3). The details of PSD in short period at different stations covering the entire country are listed in Table 2. In case the PSD of background noise (at a station) crosses beyond the standard new HNM as proposed by Peterson (1993), the seismic station will be said to be as “NOISY” station; otherwise, it is a “GOOD” station for earthquake recording. We mention that the results of the present study would be one of the indicators for investigating quality of the stations. Interestingly, we noticed noise level reduction for about 10–12 dB in short period range at almost

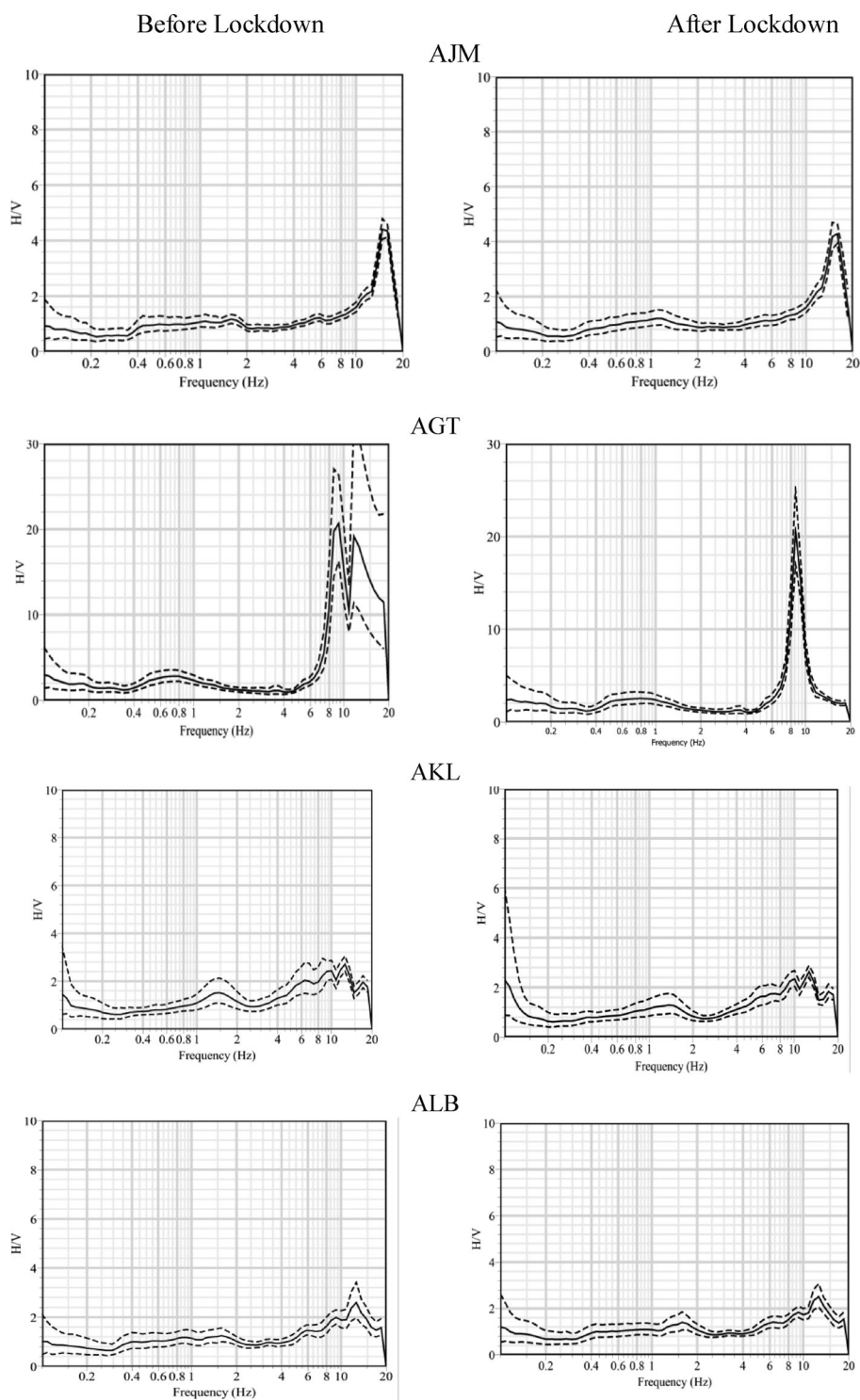


Figure 6. Estimated Horizontal to Vertical spectral ratios (HVSRs) for seismic stations of national network before (left panel) and during (right panel) lockdown is shown. Continuous solid line is the average spectral curves, while, dotted lines ± 1 standard deviation shown.

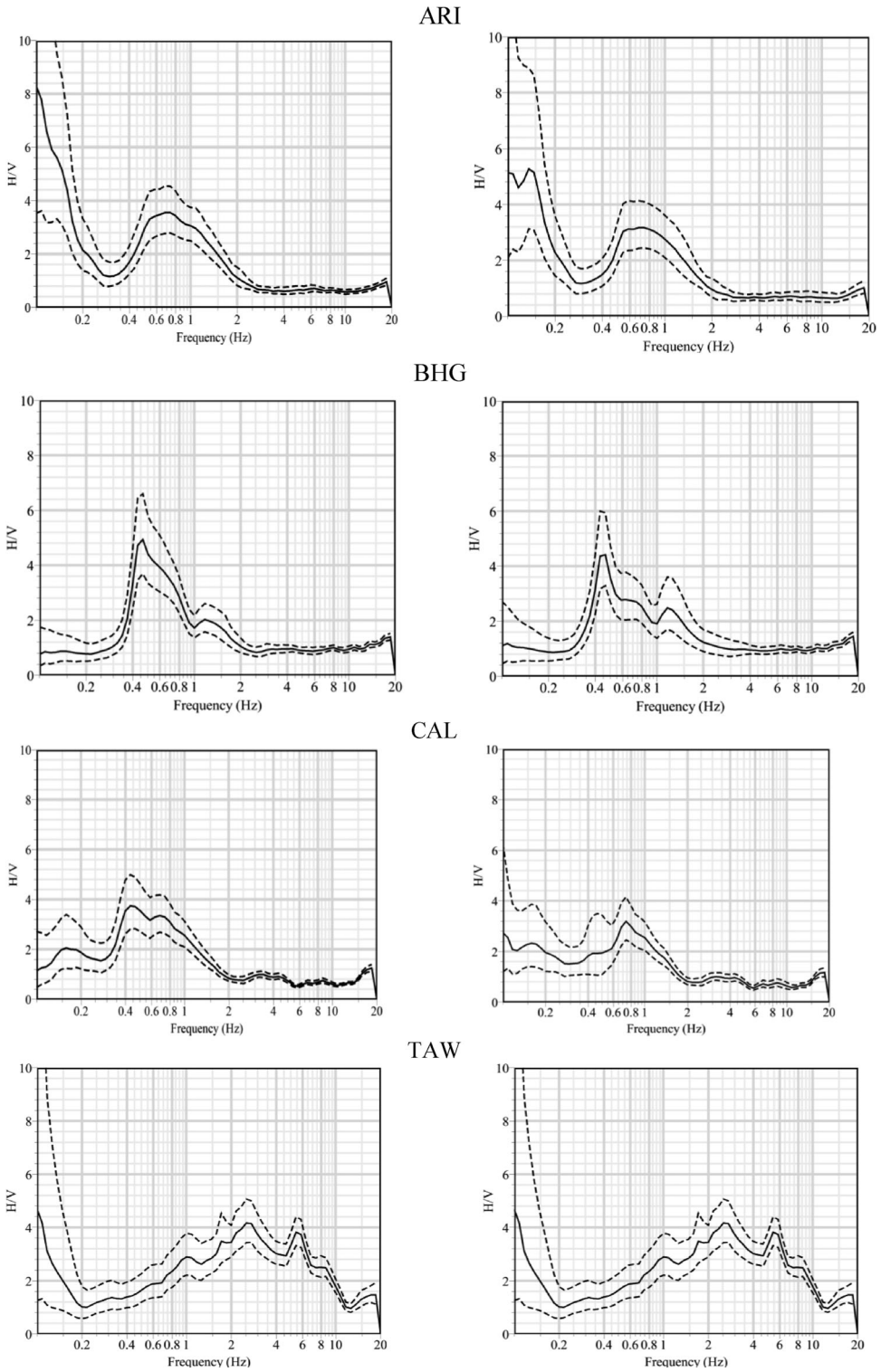


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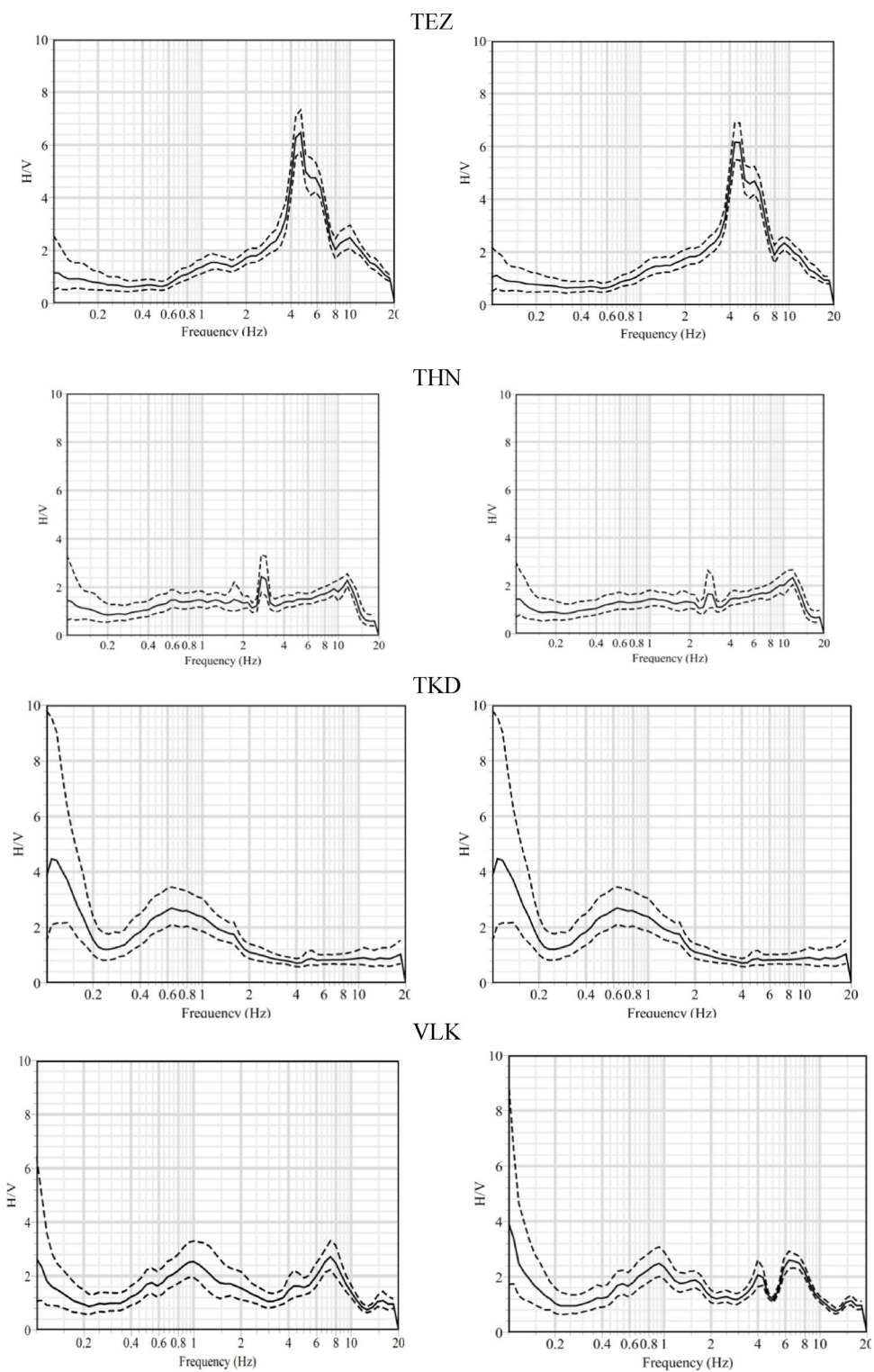
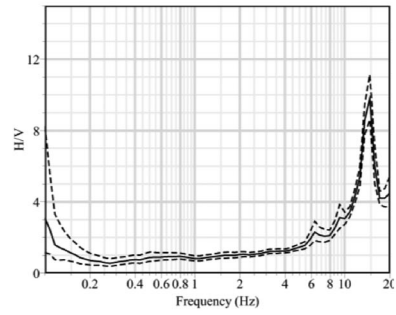
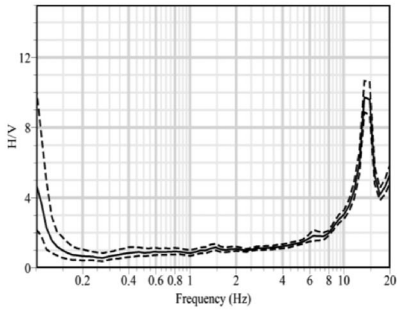
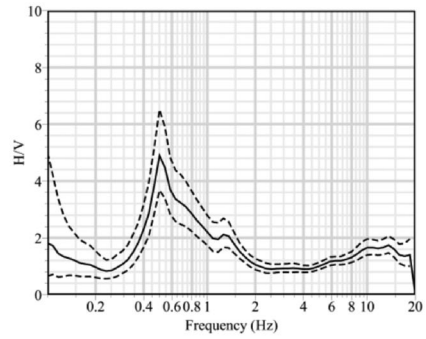
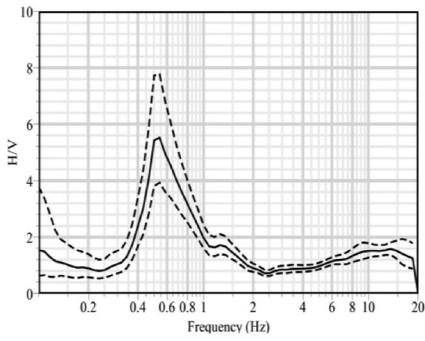


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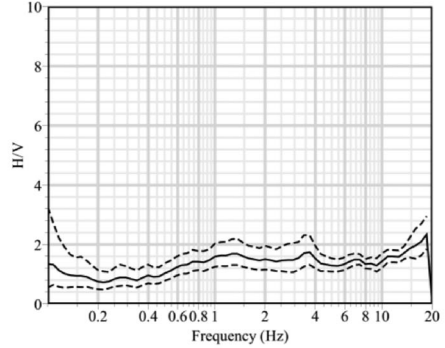
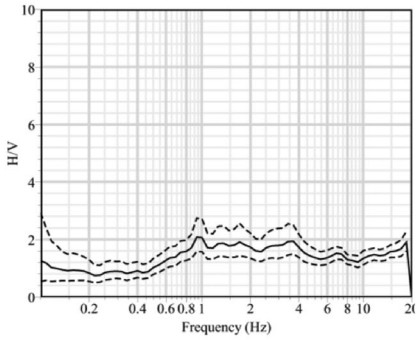
VIS



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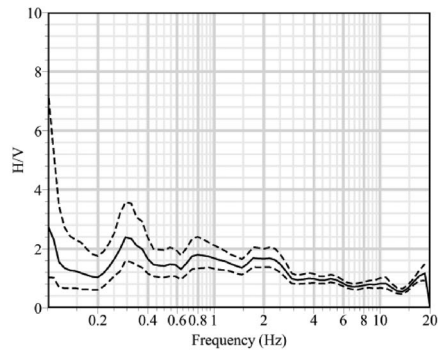
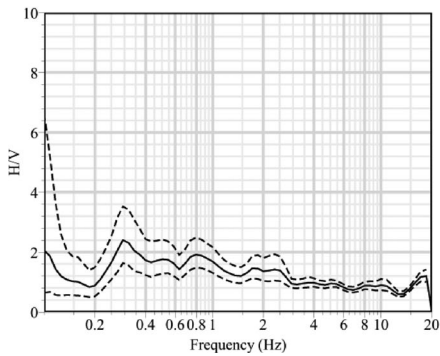


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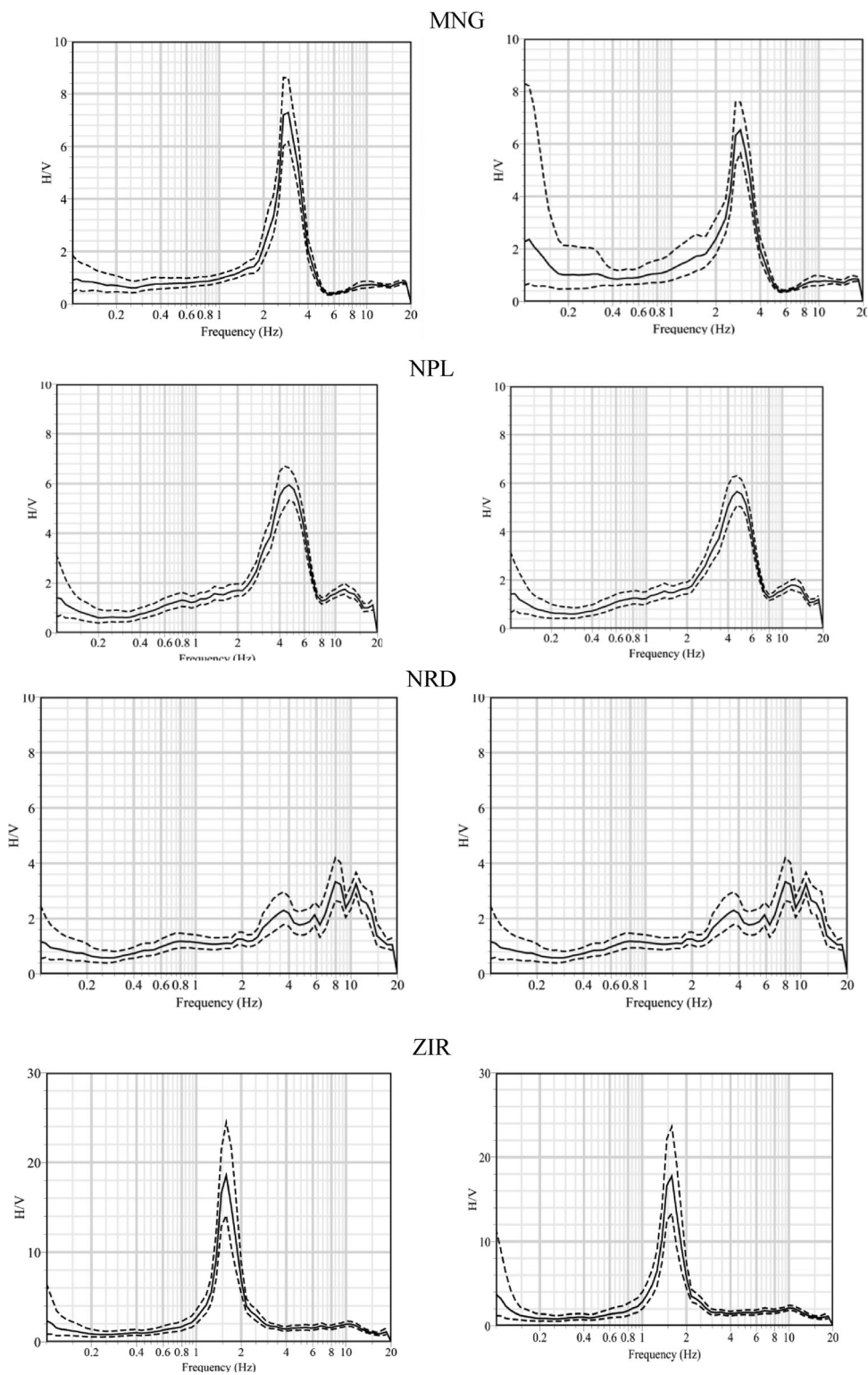


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Table 1. Estimated predominant frequency and amplification factor before and during lockdown at BBS stations (f_0 : Predominant frequency; A_f : Amplification factor).

S.No.	Station Code	Station Name	Geology	Before Lockdown f_0/A_f	During Lockdown f_0/A_f
1	TSS	Tissa	Gondwana & Vindhyan	4.00/1.93	4.00/1.44
2	THN	Thein Dam	Gondwana & Vindhyan	2.80/2.43	2.80/1.67
3	MER	Meerut	Recent Pleistocene	0.30/2.42	0.30/2.40
4	NPL	NPL Delhi	Recent Pleistocene	4.67/5.93	4.67/5.63
5	BHG	Bahadurgarh	Recent Pleistocene	0.45/4.94	0.45/4.45
6	ALB	Allahabad	Recent Pleistocene	2.00/1.43	2.00/0.93
7	VLK	Valmiki Nagar	Recent Pleistocene	0.93/2.53	0.93/2.43
8	CAL	Kolkata	Pleistocene / Tertiary boundary	0.73/3.34	0.73/3.15
9	TAW	Tawang	Cuddapah	2.59/4.22	2.59/4.21
10	TEZ	Tezpur	Recent Pleistocene	4.54/6.46	4.54/6.19
11	ZIR	Ziro	Tertiary	1.59/17.67	1.59/18.77
12	AGT	Agartala	Tertiary	8.50/20.71	2/20.61
13	AJM	Ajmer	Precambrian	15.59/4.49	2.0/4.28
14	NRD	Narmadanagar	Gondwana and Vindhyan	3.72/1.93	3.72/2.30
15	AKL	Akola	Deccan Basalt	1.45/1.28	1.45/1.32
16	VIS	Vizag	Precambrian	15.03/9.75	15.03/9.68
17	MNG	Mangalore	Precambrian	2.86/7.35	2.86/6.51
18	ARI	Jogbani	Recent Pleistocene	0.74/3.59	0.74/3.20
19	TRV	Thiruvananthapuram	Precambrian	4.05/10.14	4.05/10.94
20	UDP	Udaipur	Precambrian	2.05/0.96	2.05/0.93
21	TKD	ThakurdwaraThakurdwara	Tertiary	1.00/2.7	1.00/2.5
22	UJW	Ujwa	Recent Pleistocene	0.55/5.8	0.55/4.8
23	NRD	Narmadanagar	Recent Pleistocene	4.00/2.2	4.00/2.2

all the sites, during the lockdown situation. Geologically, these stations are installed in different set-up from older to newer formations, namely, Precambrian, Gondwana and Vindhyan, Deccan Traps, Tertiary and recent Quaternary (Figure 1b). The seismic noise levels at few urban sites, such as LKN, SRI, KOH, and GKP crossed the new HNM level between 0.1 s and 0.7 s, which may be attributed to the local site conditions and man-made activities near the stations. At some remote stations, the noise levels found lower and well confined between the new LNM and HNM curves. We emphasize that no significant change in noise level observed at these remote sites during lockdown. It characterizes the seismic stations the most suitable for seismic recoding and precise monitoring of micro- to -small earthquakes.

It is apparent from the noise spectrum (PSD) of the noisy stations located in urban agglomerations (Figure 2) that short period noise (< 1 s) reduced below the upper bracket of standard noise model (i.e., new HNM) during lockdown period. Some stations (CAL and TRV) located near the sea coast show much variation in noise levels at period < 1.0 s in both the segments (Figure 3). Source for such substantial disturbance in short period in either segment may be attributed to nearby sea coastline, which affect the station throughout the year. Some sites, which have nearby continuous source for noise due to wind, may be transmitted to ground, and therefore, it may be a reason for presence of high noise levels. However, such change in SBN could be attributed to the cultural activities of major cities.

About 46% of 115 seismic stations under national network found are located in relatively quiet places, despite, they showed $\sim 5\%$ reduction in ambient noise during lockdown situation. Apparently, these stations are located far away from the urban residential as well as industrial areas and highways. Further, it indicates that these

Table 2. Details of some representative seismic stations used in the study and their performance before and during lockdown situations.

S.N.	Station Code	Station Name	Geology	Quality of Site before Lockdown	Quality of Site during Lockdown
1	TSS	Tissa	Gondwana & Vindhyan	Good	NC
2	THN	Thein Dam	Gondwana & Vindhyan	Good	NC
3	HNL	Hanley	Gondwana & Vindhyan	Good	NC
4	GRK	Gorakpur	Pleistocene (Alluvium)	Noisy	PIM
5	JOS	Joshimath	Gondwana - Vindhyan	Good	NC
6	TKD	ThakurdwaraThakurdwara	Tertiary	Good	NC
7	MER	Meerut	Recent Pleistocene	Noisy	NC
8	NPL	NPL Delhi	Recent Pleistocene	Good	PIM
9	JMI	JMIU Delhi	Recent Pleistocene	Noisy	PIM
10	BHG	Bahadurgarh	Recent Pleistocene	Noisy	PIM
11	BKN	Bikaner	Recent Pleistocene	Noisy	NC
12	LKN	Lucknow	Recent Pleistocene	Noisy	NC
13	ALB	Allahabad	Recent Pleistocene	Good	PIM
14	GTK	Gangtok	Recent Pleistocene	Good	NC
15	VLK	Valmiki Nagar	Recent Pleistocene	Noisy	PIM
16	JPG	Jalpaiguri	Recent Pleistocene	Noisy	NC
17	SHB	Sahibganj	Recent Pleistocene	Good	NC
18	CAL	Kolkata	Recent Pleistocene	Noisy	NC
19	SIL	Shillong	Tertiary	Good	PIM
20	TEZ	Tezpur	Recent Pleistocene	Good	PIM
21	ZIR	Ziro	Tertiary	Good	NC
22	KOH	Kohima	Tertiary	Noisy	PIM
23	AGT	Agartala	Tertiary	Noisy	NC
24	BHU	Bhuj	Gondwana & Vindhyan	Noisy	PIM
25	AJM	Ajmer	Precambrian	Good	PIM
26	NRD	Narmadanagar	Gondwana & Vindhyan	Good	NC
27	GUN	Guna	Deccan Basalt	Good	NC
28	BOM	Mumbai	Deccan Basalt	Good	NC
29	AKL	Akola	Deccan Basalt	Good	PIM
30	KAD	Karad	Deccan Basalt	Good	PIM
31	LAT	Latur	Deccan Basalt	Good	PIM
32	KNT	Khunti	Precambrian	Good	PIM
33	BLS	Bilaspur	Deccan Basalt	Good	NC
34	VIS	Vizag	Precambrian	Good	PIM
35	HYD	Hyderabad	Precambrian	Good	PIM
36	VJD	Vijayawada	Precambrian	Good	PIM
37	MDR	Chennai	Recent Pleistocene	Good	PIM
38	MNG	Mangalore	Precambrian	Good	PIM
39	KOD	Kodaikanal	Precambrian	Good	PIM
40	SRI	Srinagar	Precambrian / Tertiary boundary	Noisy	NC

*PIM: PSD Improved; NC: No Change

BBS are installed on competent rocky site or in an underground vault room. Some examples of rocky sites include HNL, AJM, HYD, LAT, KOD, BLS, BHU, and PUN sites that are quietest and do not witness any noise level variations. Interestingly, 54% stations that were dominantly influenced with short period ambient noise due to growing urbanization, showed significant improvement during lockdown segment. Similar observations in seismic noise reduction during COVID-19 lockdown are reported globally (Lecocq et al. 2020; Xiao et al. 2020). In the recent Delhi earthquake sequence in April–May 2020, seismic phases from a small magnitude event M3.5 were recorded at more than 29 seismic stations and Latur (LAT) was the farthest station located at about 1100 km away from the source (Pandey et al. 2020). From a close comparison between before and during lockdown situations, we observed a

significant reduction of ambient noise in the short period range during the lockdown. Such significant reduction in the ambient noise, we attribute to sudden shutdown of countrywide cultural activities.

The Fourier spectrum of some urban stations (e.g., AGT, BOM, CAL, MNG, and TEZ) and the corresponding time histories clearly demonstrate substantial changes in amplitude during lockdown (Figure 4). The peak amplitude found varying between low and high frequencies station wise, representing dominance of local soil configuration at the site. However, the diminished amplitude values at the sites are reflected to lockdown situation. We also noticed that the patterns of all three components are remaining unchanged with frequencies but amplitudes are varying. These dissimilar amplitude variations in three components may be reflected due to randomly distributed source. However, the Fourier spectra of the horizontal components are higher in all cases compared to the vertical component (Nakamura 1989). The decrease in amplitude during lockdown collaborates well with the results obtained from PSD. The spectrograms of the SBN further reveal that the cultural activities diminished at frequencies > 1.0 Hz during lockdown condition (Figure 5). Such reduction of energy in spectrogram also support decrease in Fourier amplitude and PSD levels.

The site response plots (Figure 6) show a clear peak in all the averaged noise HVSR curves providing estimates of site amplification and the corresponding frequencies. Evidently, the predominant frequency at the site remains unchanged before and during lockdown; however, amplification factor reduced about 10% of the original value during lockdown. A higher amplification factor observed at all the seismic stations before the lockdown. Most of the stations that are located over the Quaternary geologic formation show peak amplifications at lower predominant frequencies. However, the stations located over hard rock formations like Precambrian, Gondwana - Vindhyan and Deccan traps demonstrate high predominant frequency, with relatively lower amplification factor. The results obtained using HVSR corroborates well with the findings using other approaches.

Concluding remarks

In this study, we employed various approaches to understand the characteristics of SBN before and during the lockdown situations. The following observations are made

1. SBN analysis of BBS stations under the national network has been demonstrated in the study. The PSDs of SBN are determined in the period band (0.1– 100s) using noise data free from earthquakes, instrument calibration and mass centring pulses etc. It has been observed that the noise levels are diminished about 10 - 12 dB in urban areas at period < 1.0 s during lockdown. However, the noise wavefields remained unchanged in the remote areas.
2. It has been observed that at long period and microseisms bands all the stations performed well and the noise levels were confined within new LNM and HNM, however, the performance of stations at short period (< 1.0 s) found different before and during the lockdown situations, and also it was highly influenced by cultural activities and local site conditions.

3. Fourier spectrum clearly suggests reduction of amplitude in the frequency range between 5 Hz (0.2 s) and 10 Hz (0.1 s), corroborating well with the restriction imposed on man-made activities and vehicular movements etc. during the shutdown.
4. The stations located close to the coastline are usually affected by ocean disturbances throughout the year, and hence no change in noise level observed.
5. Analysis of continuously recorded ambient seismic noise shows that horizontal-to-vertical spectral ratio (HVSr) at all the recording sites evidently indicates that the predominant frequency in the region remains stable and found independent of the lockdown situation; however, a substantial decrease in amplitude observed.
6. Objects such as trees, man-made structures and industries that cause coupling between wind energy and ground surface are prime sources of noise and need to be taken care while selecting a new site for a seismic station. In case of existing network, we opine to place the seismometers at depths below the ground surface in case noisy stations. As a result, significant reduction of ambient noise due to man-made activities and wind effects could be observed in seismic recording, which may substantially improve the monitoring of micro- to small- scale earthquakes using the national network.

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No potential conflict of interest was reported by the author(s).

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