Seismic noise analysis of broadband stations in the Eastern Ghat Mobile Belt of India using power spectral density

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ABSTRACT
The seismic background noise is studied at newly constructed sites of the Eastern Ghat Mobile Belts (EGMB), in Orissa. Ten broadband stations have been deployed along two profiles. The area has not been previously attempted for any broadband experiment. To assess the performance of the stations, we investigate the characteristics of different types of noises dominated at those sites. The power spectral densities of ambient background noise for each site are calculated and compared with the global noise model. The results suggest that the noise levels at all stations that belong to profile-1 are within the global high and low bounds. Along profile-2, the station PATN stabilizes after some time post-deployment while noise levels at other two stations are within the proposed limits. Results show that profile-1 is predominated by cultural noise, and the microseismic noise levels are observed to be low in both the profiles. Assessment of the temporal and seasonal variation of the noise has also been done, along with the calculation of the power spectral densities in the East and North components of the seismometer for this station. Overall, our observations suggest that installation of the seismometers have been successful in all the sites.

1. Introduction
Noise is the component of the signal which does not illustrate any beneficial information from the specified source, and is often in interference with the useful signal. Over the years, the analyses have revealed that noise is temporally or spatially variable, with a strong frequency dependence in nature. It can be treated as a function of location and time, varying with respect to day and season. The ambient noise is mainly composed of the surface waves whose property varies in the different period bands. It should be noted here that noise from the anthropogenic and natural sources impedes the process of unsheathing the useful details required for further analysis. The lesser the noise, the better the efficiency of the stations in detecting the earthquake signals. The essentiality of analysis of noise, its quantification and characterization is to discern the site conditions for future references (Thomas and Sheehan 2005; Abd el Aal 2013).

As a part of this study, broadband seismic stations have been deployed in the remote areas of the Eastern Ghat Mobile Belts (EGMB), in the Orissa district, between the longitudes 80°–86.5° and latitudes 17°–23°. The EGMB is girdled by the Singhbhum craton in the north, and the Bastar craton in the west. The Cuddapah basin lies south of the EGMB, while the alluvium lie to the north-east and south-east of the Eastern Ghat Belt (EGB). It is widely considered that the Proterozoic granulite...
terrane was formed during the orogenic collision of the eastern India with east Antarctica (Dobmeier and Raith 2003).

Deployment of the stations has taken place in two phases. Six out of the total of ten stations had been deployed in July 2015 and the next phase of installations took place in December 2015. BADS, RANK, RAJA, KULE, PATN and PADA stations were part of the first phase of the installations, where the stations were equipped with Trillium 120P type of sensor. Stations GPUR, DEGN, MHDR and PABN were set up in December and they were equipped with Trillium 120Q-type sensors. This area had previously never been explored by any broadband or seismic experiment. The main purpose of the study is understanding the crustal accretions in the south-eastern part of India, which would shed some light on the plate tectonic processes operating in this region, and also to make some derivations about the subsurface mineralization.

An estimate of 3600 sq. km of is covered in the study area, with the main focus of the study concentrating along different profiles. Two profiles have been set up, with profile-1 containing seven stations and profile-2 containing three working stations. The first profile is at the contact between the EGB and the Singhbhum craton, with a few stations lying in the Rengali province, while profile-2 is at the contact between EGB and the Bastar craton (Figure 1 and Table 1). The stations are

Figure 1. Station map showing the 10 installed stations along the two profiles. The stations are represented with the inverted triangles.
continuously recording data at the rate of 50 samples per second. In the entire work undertaken, the primary concern was the proper functionality of the stations. Thus, the current work mostly encompasses the comparison of the noise levels of these stations to the previously proposed U.S. Geological Survey (USGS) noise models, or figuring out the time required for stations to stabilize until they maintain a constant noise level.

The noise spectrum can be broadly classified into three frequency bands. The 0.01–0.1 Hz frequency range is the long period, 0.1–1.0 Hz is the microseism zone, and the frequency range 1.0–10 Hz is the short-period noise (McNamara et al. 2009). Atmospheric wind, tilt and the pressure are the causes of noise in the long period. The horizontal components of the broadband seismometers are mostly affected by the noise of long period. The changes in the air pressure conditions or the weather changes like storm, etc., usually do not cause changes in the microseismicity. The primary and the secondary microseisms are affected by the ocean waves and their interaction with the coast. The primary microseismic noise usually peaks at 0.2 Hz, while the secondary peak tentatively lies between 0.05 and 0.1 Hz (McNamara and Buland 2004). Though the coastal sites are most affected by the microseismic noise, the continental sites are predominantly influenced by the cultural noises. The local weather conditions also affect noise which is over 1.0 Hz frequency (Peterson 1993; Webb 1998).

### 2. Geology and tectonic settings of Eastern Ghat Mobile Belts

The EGMB is a Proterozoic granulite terrane, considered to have formed during the orogenic collisions between eastern India and east Antarctica (Dobmeier and Raith 2003), with a polychronous evolutionary history (Upadhyay et al. 2009; Bose et al. 2011) and comprises a variety of rock types including metasediment charnockites, enderbites, basic granulites, massif anorthosites and megacrystic granitoids, all metamorphosed at granulite-facies conditions. The recent geochronological data (Upadhyay and Raith 2006) reveal complex crustal architecture of the EGMB, with its complicated boundary relations with the adjacent Archean cratons (Upadhyay 2008). The craton–EGMB contact is a terrane boundary and appears as a prominent lineament in satellite images, as it is dotted by several deformed alkaline complexes marking a continental rift of Mesoproterozoic age (Upadhyay 2008). The suture zone is a highly tectonized region with a series of shear zones running sub-parallel to the contact (Biswal and Jena 1999, Gupta and Bose 2004, Gupta et al. 2005). Some of the noteworthy features of the crustal structures of the EGMB are the younging of the ages of crustal units on moving eastwards from the Bastar craton or southward from the Singhbhum craton. The contact zone is also dotted by Mesoproterozoic alkaline rock marking the presence of a former rift.

The EGMB region is therefore an interesting region from the viewpoint of crustal scale shear zone studies and also regions of focused fluid flows during metamorphism and hydrothermal alterations. The Mesoproterozoic alkaline bodies are indicative of rifts; however, since this region is seismologically unexplored, we do not have any subsurface indication of any rift. Thus, the installations of the broadband stations in the EGMB regions are the first step in study of the crustal and growth

| Station | Profile | Sensor type | Lat (°) | Lon (°) | Altitude (m) |
|---------|---------|-------------|--------|--------|-------------|
| RANK    | 1       | Trillium 120P | 20.89  | 85.14  | 90          |
| KULE    | 1       | Trillium 120P | 20.99  | 85.26  | 73          |
| BADS    | 1       | Trillium 120P | 21.29  | 85.20  | 132         |
| RAJA    | 1       | Trillium 120P | 21.47  | 85.12  | 143         |
| PABN    | 1       | Trillium 120Q | 21.13  | 85.16  | 93          |
| MHDR    | 1       | Trillium 120Q | 20.69  | 85.17  | 114         |
| GPUR    | 1       | Trillium 120Q | 20.41  | 85.29  | 64          |
| PADA    | 2       | Trillium 120P | 20.99  | 83.05  | 199         |
| PATN    | 2       | Trillium 120P | 20.71  | 83.13  | 244         |
| DEGN    | 2       | Trillium 120Q | 20.54  | 83.42  | 178         |
processes in southern India. It is an instrumental tool to shed light on the nature of the plate tectonics process operating during the Archean and the Proterozoic. Study of the mineralization process is another application to it. The Eastern Ghat Mobile Belt is divided into four lithotectonic domains by Ramakrishna et al. (1998): The Eastern and Western Khondalites, Central Migmatite and the Western Charnockites. Our study area, as previously discussed, is between the longitudes 80°–86.5° and latitudes 17°–23° which is mostly characterized by the Khondalite zone around profile-2, while profile-1 is located in the Migmatite zone.

3. Power spectral density and calculations

Power spectral density (PSD) estimates the distribution of power with the frequency. It is a standard method for quantification of the seismic background noise. The most common approach for quantification of the random seismic background noise data is the direct Fourier transform or the Cooley and Tukey (1965) method, which computes PSD via computation of the Fast Fourier transform of the original data which gives computational advantage.

In the present analysis, we use the McNamara and Boaz (2006) approach which uses the probability density function (PDF) to generate the plot to display the distribution of the PSD. PSDs are sampled over long duration from July to February, with each individual PSD curve computed using one-hour segments of the data. The data is directly used without making any prior assumptions on it. All the available data acquired are used without removal of the earthquakes, data glitches or system transients. For the direct comparison with New Low Noise Model (NLNM) and New High Noise Model (NHNM), the instrument transfer function is deconvolved with the individual time segments (McNamara et al. 2009).

Hence, for the proper analysis of the seismic stations, we have used an USGS-developed open source software PQLX, which uses the waveform and the instrument response files to generate the PSDs and PDFs (McNamara et al. 2009). The hour-long continuous time series data segments are processed by removing mean, long period trend which reduces the number of operation and long period contamination. Tapering is performed using a 10% sine function to smooth and minimize the discontinuity between the beginning and end of the time series and Fast Fourier Transform (FFT) algorithm applied. Segments are then averaged to provide a PSD and raw frequency distributions constructed by gathering the individual PSDs for each channel. Next, the raw frequencies are binned in octave intervals and distribution bins are normalized by the total number of PSDs to construct the PDF results, which are stored in server for quick access. This PSD technique described provides stable estimates over a broad range between periods 0.05 and 90 s, while the PDFs generated from the processed PSDs reduce the number of frequencies by a factor of 169, making representation in the log scale uniform (McNamara and Boaz 2006). Statistical properties such as the mode, the minimum, maximum, 10th and 90th percentile of the PSD are also plotted for each station, which helps in determining the station noise baseline and data quality. While the vertical or the Z component is the most crucial, PSD images of the other two horizontal components are also plotted.

Additionally, temporal variations in noise is studied from the representation of PSD plots of the day hours, 06.00–11.00, and the night hours 00.00–05.00, local time. Similarly, seasonal variations in the noise are analyzed, along with analysis of the noise in all three components of the broadband seismometer data. The data obtained from station RANK has been used for the illustration purposes for day/night or seasonal variations.

4. Results and discussion

As described earlier, there were 10 stations installed, spread over two arrays. The stations BADS, RANK, RAJA, KULE, PABN, MHDR and GPUR belong to profile-1 while PATN, PADA and DEGN belong to profile-2.
The PSDs generated for all the 10 stations yield that noise recorded by all the stations eventually fall within the limits of the noise model defined by Peterson (1993) despite slight instability immediately after deployment of the station. The initial high noise after deployment subsides and noise level diminishes to lie within the NHNM and NLNM as the stations stabilize. The PSDs of three stations along each of the two profiles installed are represented in the subsequent figures as examples.

Figure 2 represents the three stations of profile-1, and Figure 3 represents the PSDs of profile-2.

Station RANK, which was successfully deployed in the first phase of installation, has been yielding data since 15 July 2015. PSD representations from this station are well within the limits of the NHNM and NLNM. The short-period noise, more precisely the cultural noise, seems to be predominant at this station, with the PSDs diverging towards the NHNM. The microseismic noise levels are low, with the 10th percentile differing from the 90th percentile of the PSDs by $\sim$5–10 dB. Noise in the longer period lies within the Peterson noise model, with the 10th percentile and 90th percentile deviating from each other by $\sim$20 dB. Further perusal of this station for the two horizontal components (Figure 4) reveals the PSDs to be more noisier than the vertical component. Horizontal components being more noisier than the vertical components is accounted by the sensitivity of the seismometers to the tilts. Due to tilts, the gravity effect is coupled to the horizontal components while they are not in the vertical components (De Angelis 2008). Tilts may be caused due to barometric effects when the instruments are mounted on the surface, or due to thermal effects (Given and Fels 1993).

Figure 2. PSD plots of three stations installed along profile-1 using the data collected over the period July–February are shown as examples. (a) Station RAJA; (b) Station RANK; (c) Station GPUR. The data in station RAJA has been sampled from 15 July 2015 till 29 February 2016; similarly, station RANK has recorded data since 14 July 2015 till 29 February 2016. Station GPUR was installed in the second phase, and therefore has data from 20 December 2015 till 29 February 2016. The PSD plots clearly show the NHNM, NLNM (Peterson 1993), 10th and 90th percentile along with the mode value of the PSDs.

Figure 3. PSD plots of three stations installed along profile-2 using the cumulative data collected at each station since their deployment till February. (a) Station PADA; (b) Station PATN; (c) Station DEGN. The data has been recorded in station PADA since 03 October 2015 till 29 February 2016, while for station PATN, the data from 01 January 2016 till 29 February 2016 has been used. Station DEGN has data recorded from 20 December 2015 till 29 February 2016. The figure clearly indicates the NHNM, NLNM, 10th and 90th percentile along with the mode of the PSDs values.
Predominance of cultural noise has been a common observation in all the stations of the first profile. For station KULE, the short-period noise predominantly lies close of the higher noise limit, with the 90th percentile partially lying beyond the proposed noise model level in the 0.2–0.9 s period, while for the longer period noise, the PSD diverges towards the lower noise limit. The PSD plot of station PADA displays that for cultural noise, the 10th percentile of PSDs deviates by about 25 dB from its 90th percentile, with the mode mimicking the 10th percentile of PSDs between the time period 0.1 and 1 s, and below 0.1 s period, mode of the PSDs shifts closer to the 90th percentile. Microseisms have lower variation in this station, and generally are quieter, with a fluctuation of ~5–7 dB.

Similar to station PADA, station PATN also registers a wide variation (~30 dB) between the 10th and 90th percentile PSDs in the longer period noise but mostly concentrating towards the 10th percentile. Here it is to be noted that the PSD representation for PATN station has been done using data over the period of December–February. While most part of the noise can be restricted between the 10th and the 90th percentile, some noise does spread beyond the 90th percentile PSDs. These noise can be deemed to be due to transients, glitches or spikes, while for the noise lying below the 10th percentile may be due to the short data gaps.

PADA and PATN belong to the same profile, and hence the analogy in the longer period noise. While stations like PATN and PADA, profile-2, are severely affected by the cultural noises, station RAJA, profile-1, has the less prominence of the cultural noise, with small variation of about ~5 dB. Microseismic noise is less, and can be considered to be almost quiet.

The four stations DEGN, profile-2, and GPUR, MHDR, PABN, profile-1, show similarity in their PSD distributions. In the microseism zone, there is approximately 4–5 dB variation between the 10th and the 90th percentile of the PSDs, while the long-period noise have wide variation in PSD, with the mode of the PSDs almost overlapping the 10th percentile beyond 50 s period. All the stations display an overall uniform noise patterns in the PSD PDF plots, and thus it is safe to conclude that overall geology brings little difference in the noise levels between different stations and the stations are stable. However, the cultural noise variations are station specific and change as per human activities along each site. The microseismicity is stable and the stations are neither affected by the coastline nor have huge waterbodies in the close proximity. However, an overall observation is that the long-period noise is lower than the low-period noise (cultural noise) in all the stations.

4.1. Day and night comparisons

The effect of the cultural noise can be distinguished in studying the patterns of the PSD distributions of the day and the night. We have considered the station RANK for the study purpose, and the PSDs
analyzed for spectral noise (Figure 5). For the day time, the PSDs are sampled using 1-hour segments from 06.00 to 11.00 hours. The PSD plot shows considerable noise in the short period with the PSD distribution slightly above the NHNM (0.2–0.8s). Microseismic noise is low during the day time. Likewise, the night time 12.00–05.00 hour data has been sampled as PSDs. The cultural noise during night is lower than the day time, while the microseismic noise level is unperturbed temporally.

4.2. Seasonal variation comparisons

Station RANK was also analyzed for the seasonal variation (Figure 6). The PSDs sampled over the months July–August, the monsoon season, show a higher level of microseismic noise than those over the other seasonal plots. PSDs sampled for the months September–November together for the autumnal season exhibit a lower level of microseismic noise, with variation over 10 dB between the 10th and 90th percentile PSD. For the winter season, PSDs sampled for December, January and February present a lesser deviation between the 10th and 90th percentile of the PSDs, in comparison to the autumnal or the monsoonal seasons with an overall upward trend in the long-period noise. The low temperatures during the winter months could be a prime reason for the less variations. The microseismic noise is also less spread, with variation between 10th and 90th percentile being <10 dB; however, the cultural noise level remains the same irrespective of the season.
5. Conclusions

The essentiality of the noise analysis is to verify the data quality and also acts as a test to the time taken by the seismometer to stabilize before it yields a workable data (Thomas and Sheehan 2005; Abd el Aal 2013). Therefore, comparing the PSDs in both the profiles, it reveals that profile-1 is more dominated by cultural noise than profile-2. Station RANK registered high cultural noise in the vertical component, which is further higher upon considering the horizontal components. The plots of PSDs for the horizontal components for station RANK reveal that the short periods were noisier than the vertical components. The same trend followed in the long period where the horizontal components were noisier than the vertical period and it extended outside the NHNM. However, this noisier horizontal component can be a manifestation of the sensitivity of the seismometers to the tilt.

Day/night variation studies divulge that day time registers more cultural noise over night time. While the microseismic noise are of the same level in all the stations temporally, seasonally the distinction in the microseismic noise can be noted. Microseismic noise which is mostly caused by water waves in oceans or the lakes show a surge in the noise level in monsoonal months in comparison with autumn or winter.

However, the overall analysis of the PSDs from each individual stations verifies that the installations of the seismometers have been successful in all the stations. The PSD plots of the stations of profile-1 have produced workable data along with noise within the USGS-proposed limits. Along profile-2, stations PADA and DEGN have shown good quality of data usable for further processing since the installations, while for station PATN, the data stabilized after some time post the installations.

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