

Performance Evaluation of Broadband Seismic Stations in Central India Tectonic Zone: Characterization of Ambient Noise Environments

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Abstract

This study examines spatiotemporal variations of ambient noise recorded at nine temporarily deployed broadband seismic stations (July 2023-to-March 2025) in the Central Indian Tectonic Zone (CITZ) across diverse geological settings, from unconsolidated Quaternary sediments to solid basement rocks, to assess seismic data quality and ambient noise environments. Data were analyzed using power spectral density (PSD) and root mean square (RMS) ground displacement across multiple frequency bands. PSD analysis reveals that vertical component (BHZ) ambient noise at all stations meets global noise standards, confirming recording quality. In contrast, horizontal components (BHE and BHN) show increased PSD over long durations (> 20 s), far exceeding global noise standards. RMS ground displacement in the short-period range (0.1-1 s or 1–10 Hz) is driven by anthropogenic sources. Stations on Quaternary deposits exhibit elevated PSD and ground displacement in the short-period range due to site amplification. Ground displacement and PSD show significant variability in the intermediate period range (1–10 s or 0.1-1 Hz), especially during monsoon, due to precipitation, surface pressure, and cyclones. These findings highlight the interplay of lithology, anthropogenic activities, and hydrometeorological influences on ambient noise, offering critical insights for understanding hydrometeorological elements through seismology and optimizing seismic networks for noise-based imaging.

1. Introduction

A seismogram records ground motions produced by continuous Earth vibrations resulting from both natural processes and anthropogenic sources. The natural sources include wind, rainfall, river flow, ocean-generated microseisms, and earthquakes, whereas anthropogenic noise mainly arises from human activities, industrial operations, and vehicular traffic (Webb, 2002; Zürn and Widmer, 1995; McNamara and Buland, 2004; Wilson et al. 2002; Withers et al. 1996; Beauduin et al. 1996). "Ambient noise" denotes continuous ground vibrations produced by various sources, characterized by frequency, and displaying distinct temporal and spatial variability. Ambient noise levels influence the quality of seismic signals captured by broadband seismometers, as diverse noise sources hinder ground-motion recordings. Ambient noise is classified into three different categories based on frequency range, kind of motion, presumed sources, and the estimated distance from its origins: Long-period noise (0.01–0.1 Hz, 10–100 s), microseism noise (0.1–1.0 Hz, 1–10 s), and short-period noise (1.0–20 Hz, 0.05-1 s) (Carter et al., 1991; McNamara and Buland, 2004; McNamara and Boaz, 2006; Bormann and Wielandt, 2013; Dybing et al., 2019). A comprehensive classification of noise categorizes the spectrum into six discrete period bands (Fig. 2): short-period (0.1–1 s), body wave dominant (1–5 s), secondary microseisms (5–10 s), primary microseisms (10–20 s), intermediate period (20–50 s), and long-period (50–100 s) (Anthony et al., 2015). Long-period noise primarily arises from temperature fluctuations, instrumental tilt, wind activity, volcanic activity, and atmospheric pressure variations. The horizontal components of seismometers are predominantly influenced by long-period noise (Sorrells, 1971; Beauduin et al., 1996; Tanimoto, 2005; Zürn et al. 2007; Nishida, 2017; Smith and Tape, 2019). The primary microseisms originate when ocean waves directly impact the seafloor (Hasselmann, 1963; Anthony et al., 2015;

Huang et al., 2022). Secondary microseisms arise from the superposition of ocean waves propagating in opposing directions (Longuet-Higgins, 1950; Anthony et al., 2015). The short-period band includes noise generated by cultural activities, including human activities, vehicular traffic, industrial equipment, and other anthropogenic sources (Nakata et al., 2019). The river currents generate transient short-period noise primarily because of turbulent flow and bed-load transport, with amplitudes modulated by hydrological cycles (Burtin et al., 2008).

Quantitative measures obtained from power spectral densities (PSD) provide a robust framework for examining ambient noise levels and their temporal evolution (McNamara and Buland, 2004). The long-term PSD distributions are examined relative to established global reference noise models, such as the New Low Noise Model (NLNM) and New High Noise Model (NHNM), to determine whether recorded spectra fall within acceptable operational limits and to identify frequency bands affected by persistent environmental or site-related noise (Peterson, 1993; McNamara and Buland, 2004; McNamara and Boaz, 2006; Anthony et al., 2015; Smith and Tape, 2019). In addition to the PSD measurements, the root mean square (RMS) ground displacement derived from PSD provides a robust and physically meaningful measure of ambient noise amplitude across several frequency bands. Ambient noise levels are non-stationary, exhibiting variation with air pressure, precipitation, and cultural activities. RMS time series have been widely employed to quantify temporal noise variability and to investigate linkage with anthropogenic activities, hydrometeorological influences, and site conditions (Lecocq et al., 2020; Dybing et al., 2019; Anthony et al., 2015).

A comprehensive assessment of ambient seismic noise has been extensively performed across worldwide broadband networks to assess seismometer efficacy and environmental impacts (Peterson, 1993; McNamara and Buland, 2004; Anthony et al., 2015; Smith and Tape, 2019; Lecocq et al., 2020; D'Alessandro et al., 2021; Uthaman et al., 2022). Prior research in India has predominantly concentrated on station performance and microseismic activity (Jha et al. 2023; Saha et al. 2024; Jana et al. 2017; Pandey et al., 2020; Uthaman et al., 2022; Maitreyi et al., 2024), thereby creating a gap in comprehending the influence of environmental factors on broadband noise within tectonically intricate continental interiors. However, in the Central India Tectonic Zone (CITZ), particularly the Satpura Gondwana Basin (SGB) and its nearby areas, ambient seismic noise studies have not previously been carried out, especially those examining the synergistic impacts of lithology and hydrometeorology on broadband seismogram noise variability.

The CITZ is a prominent east-west-oriented mobile belt that divides the Indian Craton into northern and southern Indian cratonic blocks (Roy and Prasad, 2003; Radhakrishna and Naqvi, 1986) (Fig. 1). The northern Indian Block comprises the Bundelkhand-Marwar Craton, while the southern Indian Block has the Bastar, Dharwar, and Singhbhum Cratons. The two blocks were amalgamated in the Proterozoic, forming the Greater Indian Landmass (Bhowmik et al., 2014). The SGB is located on the Pachmarhi Plateau within the CITZ in central India. It spans over 12,000 km² and has almost 5,000 meters of deposition from the Gondwana period. The basin is delineated by Vindhyan sediments to the north, granitic gneiss to the south, and Deccan traps to the east and west (Chakraborty and Ghosh, 2005; Singh

et al., 2015). The morphology of the region indicates that the sediments of the SGB are at a higher elevation than the surrounding rock formations (Singh et al., 2015). The basin is unique among the Indian Gondwana basins because of its extensive geological record, spanning from the Permian to the Cretaceous period (Chakraborty and Ghosh, 2005).

A temporary network of nine broadband seismic stations was deployed across the SGB in the CITZ to investigate the evolution of the SGB and its surrounding region (Fig. 1). To accomplish this goal, it is imperative to comprehend the station's functionality performance, characterize ambient noise levels, and examine their relationship with geological setting and hydrometeorological variability across multiple frequency bands. The present study evaluated the performance of seismic stations and characterized the ambient noise environments of SGB and adjacent areas utilizing seismic data from nine temporarily installed broadband seismic stations (Fig. 1). We examined PSD and RMS ground displacement at each seismic station during their operational lifespan and compared these with subsurface geological conditions and hydrometeorological characteristics across several frequency ranges. This study provides a first-order ambient noise reference for the SGB and its nearby areas, a tectonically and lithologically heterogeneous zone where geological setting and hydrometeorological forcing strongly modulate seismic noise characteristics. This study offers a useful framework for future noise-based imaging and environmental seismology studies in central India.

2. Data and methods

2.1 Data

Nine seismic stations have been installed on the western side of the CITZ, in and around the SGB. We install Trillium compact sensors above the surface at each seismic station. These sensors are mounted on rectangular concrete piers enclosed within concrete housings. The surface soil was excavated to a depth of about 0.5-1.0 m to remove loose topsoil before the concrete piers were cast on compacted subsurface material. An air gap is maintained between the pier and the surrounding housing walls to minimize the transmission of ambient noise-induced vibrations to the seismometers. This design effectively isolates the pier from wind-induced forces acting on the outer housing, minimizing tilt-related disturbances. The installed seismic stations have been continuously collecting data at a sample rate of 50 Hz. Each seismic station is equipped with a 24-bit digitizer, a 3-channel broadband seismometer (Trillium compact sensor), two 12 V/100 Ah dry batteries for power, two solar panels for continuous battery charging, a global positioning system for precise time and location data, and two charge controllers to manage the battery charging.

The network configuration was completed in three stages of installation, with three stations (SG01, SG02, and SG03) installed in July 2023 for the first phase, three stations (SG04, SG05, and SG06) in March 2024 for the second phase, and three stations (SG07, SG08, and SG09) in October 2024 for the third phase (Fig. 3). Data from all stations is continually recorded and sampled at rates of 50 samples

per second (50 Hz). We collected time series data (miniSEED format) from these installed broadband seismometers from July 2023 to March 2025 for seismic noise analysis.

To complement the seismic dataset, we utilized daily cumulative precipitation and daily mean atmospheric surface pressure data for the region encompassing all nine seismic stations (SG01 to SG09). Precipitation and surface pressure data were obtained from the ERA5 reanalysis dataset via the Copernicus Climate Data Store (C3S, 2024) at a spatial resolution of $0.25^\circ \times 0.25^\circ$ (Hersbach et al. 2023, <https://doi.org/10.24381/cds.adbb2d47>). Precipitation data consists of daily sums derived from hourly measurements, whereas pressure data are daily means calculated from hourly data. These meteorological parameters were used to examine potential seasonal or synoptic-scale influences on the ambient noise environment.

2.2 Methodology

This study utilizes power spectral density and root mean square (RMS) ground displacement estimates to assess the efficacy of seismic stations, monitor ambient seismic noise, and identify their dominant sources. The primary tool used is PQLX (Portable Quake Locator eXtended) (McNamara and Boaz, 2006), which calculates probability density functions (PDFs) derived from the PSDs of the vertical and horizontal seismic signals. The PQLX is an open-source system designed to assess seismic data quality and station performance using a client-server architecture along with data extraction and manipulation tools. For a given set of waveform data and corresponding instrument response files, PQLX calculates trace statistics and generates PSD estimates. PSD computations follow the methodology outlined by McNamara and Buland (2004), enabling evaluation of noise levels across frequency bands. The resulting PDFs offer analyses of power amplitude variations as a function of period, facilitating direct comparisons of seismic noise levels at different stations against standard reference models, such as the New High Noise Model (NHNM) and the New Low Noise Model (NLNM) (Peterson, 1993). These comparisons help in evaluating station performance, identifying noise sources, and tracking variations over time. To obtain an independent proxy for site response, we computed the horizontal component (H), vertical component (V), and H-V difference in dB from ambient seismic noise (D'Alessandro et al., 2021; Jha et al., 2023). The horizontal spectrum was obtained as the geometric mean of the north–south and east–west components.

RMS ground displacement was computed using the SeismoRMS Python package (Lecocq et al., 2020), which integrates the PSD over specified frequency bands and converts the result into displacement units using instrument response functions. Daily median RMS displacement values for each seismic station were computed for long-period (0.01–0.1 Hz), microseism band (0.1–1 Hz), and short-period (1–20 Hz) frequencies and subsequently compared across stations and time periods to identify temporal variability and site-specific differences. Statistical comparisons were conducted between RMS displacement values and meteorological parameters to assess environmental influence on seismic noise levels.

3. Results and Discussion

3.1 Power Spectral Density Characteristics and Site Response

The PSD analysis of all nine broadband seismic stations (SG01 to SG09) reveals frequency-dependent noise characteristics that vary systematically with component orientation and local geological conditions (Figs. 4 and S2). Across the period range, PSD estimates for all stations lie within the bounds of the NLNM and New NHNM (Peterson, 1993), confirming the acceptable broadband performance of the temporary network and the suitability of the recorded data for seismological investigations.

Substantial spatial variability is observed at periods shorter than 1 second (frequencies > 1 Hz). Stations SG01, SG04, and SG06 have systematically elevated PSD amplitudes compared to SG08 and SG09, with differences reaching 5–10 dB below the 0.5 s period (Fig. 5a). This pronounced high-frequency amplification corresponds precisely with the geological context of these stations: SG01, SG04, and SG06 are situated on unconsolidated Quaternary alluvium (Fig. 1), whereas SG08 and SG09 are installed on hard basement rocks. According to theoretical and empirical studies, unconsolidated near-surface materials trap and amplify high-frequency seismic energy due to sharp impedance contrasts with underlying competent formations (Borcherdt, 1970; Bonnefoy-Claudet et al., 2006).

Within the microseism band (1–10 s), station-to-station variability remains limited, indicating that the sources generating these signals are regional in scale and affect all sites relatively uniformly (Fig. 5a). The primary microseism peak (10–20 s) is comparatively weaker across the network, suggesting that direct ocean wave interaction with the coastline (Longuet-Higgins, 1950) contributes less significantly to the ambient noise field in this regionally located network. All stations show a consistent secondary microseismic peak between 3 and 8 seconds. This corresponds to the well-documented double-frequency microseism generated by non-linear interactions of opposing ocean waves (Hasselmann, 1963; Ardhuin et al., 2015).

At periods longer than 20 s, a consistent and systematic pattern emerges across all stations: horizontal components (BHE and BHN) exhibit elevated PSD levels compared to vertical components (BHZ), with horizontal amplitudes frequently approaching or exceeding the NHNM (Figs. 4 and S2). This component-dependent behaviour is clearly illustrated in the median PSD plots (Fig. 5a–b), where the geometric mean of horizontal components shows progressively increasing separation from the vertical component at long periods. Such observations are widely attributed to tilt-induced noise, wherein horizontal seismometers respond not only to translational ground motion but also to minute tilts that couple gravitational acceleration into the seismic records (Rodgers, 1968). Environmental factors, such as fluctuations in barometric pressure (Sorrells, 1971; Beauduin et al., 1996), diurnal thermal expansion and contraction (Benioff, 1935; Zürn and Widmer, 1995), and local cultural vibrations (McNamara and Buland, 2004), can all produce tilt signals, with horizontal sensors being more affected than vertical components because they are more sensitive to tilting.

The H-V difference (in dB) curves (Fig. 5c) provide additional quantitative insight into frequency-dependent site response. The negative values (< 0 dB) of the H-V difference show that the noise PSD values are higher on the horizontal component than the vertical component, and vice versa. Most stations show negative H-V (in dB) across short and microseismic period bands, with the exception of SG08 and SG09, which are located at unclassified basement rocks and have near-zero or positive values. For the long-period range, all seismic stations show substantially higher noise PSD values on the horizontal component than the vertical one. The results corroborate with Webb and Lee (2002) observation that the horizontal component of long-period noise is approximately 10–40 dB higher than the vertical component at stations installed on the surface.

In addition, the H–V curves display broad maxima rather than narrow, well-defined peaks, and no distinct single resonance frequency is observed at any station. This pattern suggests broadband amplification rather than resonance confined to a specific frequency, which is characteristic of sites with complex near-surface velocity structure or significant impedance contrasts distributed over depth. These characteristics are common in weathered or heterogeneous near-surface environments, distinguishing them from simple sedimentary basins with well-defined fundamental resonance frequencies (Nakamura, 1989; Bonnefoy-Claudet et al., 2006; Molnar et al., 2022).

This multi-frequency noise framework provides a comprehensive understanding of ambient noise sources in the region and has practical implications for seismic network operations. Stations on unconsolidated sediments (SG01, SG04, SG06), while providing valuable data on site response and local noise sources, may benefit from specialized processing techniques to mitigate the strong high-frequency amplification. Conversely, stations on hard rock (SG08, SG09) offer exceptionally quiet recording conditions ideal for detecting low-amplitude teleseismic and regional events. The clear separation of source regimes by frequency band enables targeted filtering strategies to optimize signal-to-noise ratios for specific seismological applications, from local earthquake monitoring to ambient noise tomography and tectonic studies.

3.2 Spatiotemporal Variability and Noise Source Characterization

Long-Period Band (0.01–0.1 Hz):

The temporal fluctuation of daily RMS ground displacement in the long-period band (0.01–0.1 Hz) exhibits gradual variability with limited spatial contrast across the network (Fig. 6a). While some stations (e.g., SG01–SG03) have consistently low noise levels throughout the deployment period, others display modest amplitude modulations that appear broadly correlated with seasonal transitions. The limited spatial variability in this band (Fig. 6a), despite significant lithological differences among sites (Fig. 1), suggests that long-period noise sources operate on regional or larger scales. This may reflect the fact that the wavelengths associated with these low-frequency signals (tens to hundreds of kilometers) are large compared to the network aperture, resulting in coherent wavefields across the array. However, subtle differences among stations, such as the slightly elevated amplitudes at SG08 and SG09 during

certain periods, may indicate local site-specific sensitivity to environmental forcing, presumably due to fractured basement geology and groundwater dynamics (Bettinelli et al., 2008). Long-period seismic fluctuations in continental settings are known to arise from multiple environmental processes, including oceanic infragravity waves (Webb, 1998), barometric pressure loading (Sorrells, 1971; Beauduin et al., 1996), atmospheric weather systems (Nishida, 2017; Tanimoto, 2005), and hydrological loading associated with aquifer dynamics and surface water redistribution (Bettinelli et al., 2008; Smith and Tape, 2019). Similar long-period environmental signals have been systematically documented in broadband stations globally, with pressure-induced ground tilts producing characteristic signatures in horizontal components (Zürn et al., 2007; Anthony et al., 2015).

Intermediate-Period Band (0.1–1 Hz):

The intermediate frequency band (0.1–1 Hz) exhibits coherent temporal variability across all nine stations, with pronounced amplitude increases during monsoon months (June–September) and documented cyclone events (Fig. 6b). This coordinated response across stations strongly indicates a regional forcing mechanism independent of local site conditions. The timing of elevated RMS amplitudes corresponds closely with periods of increased precipitation and reduced atmospheric pressure (Fig. 7). Throughout the study period, multiple tropical cyclones affected the region, including Cyclone Tej (October 2023), Hamoon (October 2023), Midhili (November 2023), Michaung (December 2023), Remal (May 2024), Asna (August–September 2024), Dana (October 2024), and Fengal (November–December 2024). Each of these events coincides with notable peaks in ground displacement within the 0.1–1 Hz frequency band (Fig. 7), consistent with previous observations that tropical cyclones generate enhanced microseismic energy through intensified ocean wave interactions (Retailleau and Gualtieri, 2021). Notably, Cyclone Asna directly impacted the Madhya Pradesh state, encompassing the study region, and produced particularly pronounced amplitude excursions.

Quantitative correlation analysis (Figs. S3 and S4) reveals systematic relationships between RMS amplitudes and meteorological parameters. There are negative correlations with atmospheric pressure (mean Pearson's $R = -0.62 \pm 0.09$ across stations) and positive correlations with precipitation (mean $R = 0.53 \pm 0.11$), with basement stations (SG08, SG09) showing weaker relationships than stations atop sedimentary cover. This pattern suggests that, while the primary source of microseismic energy is regional (ocean wave interactions), the local expression of this energy is modulated by site-specific geological conditions. The inverse relationship with atmospheric pressure is consistent with pressure-induced elastic deformation of the solid Earth, wherein reduced atmospheric loading decreases compressive stress at the surface, allowing crustal rebound and enhanced ground motion (VanDam and Wahr, 1987). Positive correlations with precipitation may reflect rainfall-induced changes in near-surface shear strength and pore pressure, which affect the coupling of seismic energy into the ground (Oakley et al., 2021). The coherent temporal variability across stations, combined with the absence of correlation with infrastructure density (Fig. S1), firmly establishes that the 0.1–1 Hz band is dominated by natural, environmentally driven sources rather than anthropogenic activity.

Short-Period Band (1–20 Hz):

The short-period band (1–20 Hz) exhibits the most pronounced spatial variability among the three analyzed frequency ranges (Fig. 6c). Stations SG01, SG04, and SG06 have peak RMS amplitudes of 45–50 nm, whereas SG08 and SG09 are constantly below 10 nm. This substantial amplitude variability (factor of 4–5) far exceeds the variability observed in longer-period bands, strongly implicating local site characteristics and proximal noise sources as the primary regulating factors. The spatial distribution of short-period amplitudes is substantially correlated with infrastructure density and population distribution.

(Fig. S1). Stations exhibiting elevated amplitudes (SG01, SG04, SG06) are located closer to road and rail lines (Fig. S1b) and in areas of relatively higher population density (Fig. S1a). This correlation provides direct proof that anthropogenic activity, particularly transportation-related vibrations, is the predominant cause of short-period seismic noise in the studied region. The absence of such correlation in longer-period bands supports the notion that different frequency bands sample fundamentally distinct source processes.

The hourly probability density distributions of ground displacement reveal a significant diurnal modulation of short-period energy (Fig. 8). Most stations exhibit systematic daytime amplitude amplification between approximately 06:00 and 18:00 Indian Standard Time (IST), while nighttime amplitudes are substantially reduced. This pattern is notably visible at all stations except SG01, which are located in proximity to roads, railways, human settlements, and water bodies (Fig. 1). The diurnal cycle corresponds precisely with typical periods of human activity, including vehicular traffic, agricultural operations, and construction activities. Such diurnal patterns are a well-documented signature of cultural seismic noise in continental broadband networks (e.g., McNamara and Buland, 2004; Lecocq et al., 2020), indicating that human activities significantly influence seismic measurements during specific times of the day.

Station SG01 is an intriguing exception to the diurnal pattern: it is adjacent to a continuously flowing canal and experiences elevated noise levels both day and night, suggesting that persistent water flow generates continuous high-frequency energy independent of diurnal activity cycles (Burtin et al., 2008). Furthermore, stations SG04 and SG06 had significantly lower noise levels during the monsoon season, beginning around 26 July (Figs. 6c, 8d, and 8f). This seasonal suppression of high-frequency energy is likely due to decreased anthropogenic activity during periods of heavy rainfall, when outdoor activities such as traffic and construction diminish (Bettinelli et al., 2008).

3.3 Lithological Control on Site Response

The systematic connection between elevated short-period PSD amplitudes (Fig. 5a), positive H–V differences (Fig. 5c), higher RMS displacements (Fig. 6c), and seismic stations in diverse geological environments (Fig. 1) demonstrates that local geology exerts a first-order control on high-frequency site response. Stations SG01, SG04, and SG06, all located on alluvial deposits, exhibit the most pronounced

amplification. This amplification happens because of several physical processes: (1) sharp impedance contrasts between low-velocity surface sediments and higher-velocity underlying formations trap seismic energy within the sedimentary layer (Borcherdt, 1970); (2) resonance effects related to sediment thickness and velocity structure can produce frequency-dependent amplification (Bard and Bouchon, 1985); and (3) multiple scattering within heterogeneous near-surface materials prolongs the duration of ground motion (Bonilla et al., 1997). Stations installed on progressively more lithified formations exhibit correspondingly reduced high-frequency amplification. SG02, SG03, and SG05, located on Gondwana Supergroup sediments (Fig. 1), show moderate amplification (Figs. 5a and 6c), consistent with intermediate mechanical rigidity (Molnar et al., 2022). SG07, located on Vindhyan Supergroup sediments, shows transitional behavior, reflecting the greater stiffness and lower attenuation characteristic of these compact sedimentary rocks. SG08 and SG09, located on hard basement rocks, exhibit minimal high-frequency amplification and provide exceptionally clear recordings of low-frequency signals (Fig. 6), attributable to reduced attenuation and effective coupling with deep Earth structures (Anderson and Hough, 1984).

Conclusions

This study presents a characterization of ambient seismic noise across the CITZ, particularly in and around the SGB, using data from a temporary broadband seismic network. The analysis of probabilistic PSD, spectrograms, and ground displacement time series across multiple frequency bands provides the following main observations:

1. The PSD analysis conducted across all frequency bands demonstrates that the vertical component (BHZ) noise levels at all stations consistently meet global noise standards, thereby confirming the quality of recordings. In contrast, the horizontal components (BHE and BHN) frequently exhibit elevated PSD levels over long periods (> 20 s), which frequently surpass the global noise standards at all seismic stations.
2. Station-to-station variations in high-frequency noise indicate a strong influence of local site conditions. Stations on unconsolidated sediments (SG01, SG04, and SG06) show elevated short-period (1–20 Hz) amplitudes, whereas stations on relatively harder lithologies (e.g., SG08 and SG09) exhibit comparatively lower amplitudes.
3. The frequency-dependent nature of ambient seismic noise suggests that dominant processes vary across spectral bands. Short-period noise has considerable diurnal variability and is spatially associated with populated areas and transportation corridors, indicating a significant anthropogenic contribution. In contrast, variability in the intermediate and long-period bands is consistent with regional microseism activity and variable environmental forcing.
4. Temporal variations in noise levels exhibit both diurnal and seasonal patterns. High-frequency amplitudes increase during daytime hours, reflecting increased human activity, whereas reduced amplitudes are observed during periods of sustained rainfall. Seasonal increases in intermediate-band amplitudes are associated with monsoon and cyclone activity, highlighting the influence of regional meteorological processes.

Overall, the results demonstrate that ambient seismic noise in the CITZ region is controlled by a combination of local site conditions, anthropogenic activity, and regional environmental forcing, with different mechanisms dominating different parts of the seismic spectrum.

Declarations

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Data availability

The waveform data used in this investigation are available on request from the corresponding author.

Disclosure statement

The authors declare no competing interest.

Funding Declaration

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Figures

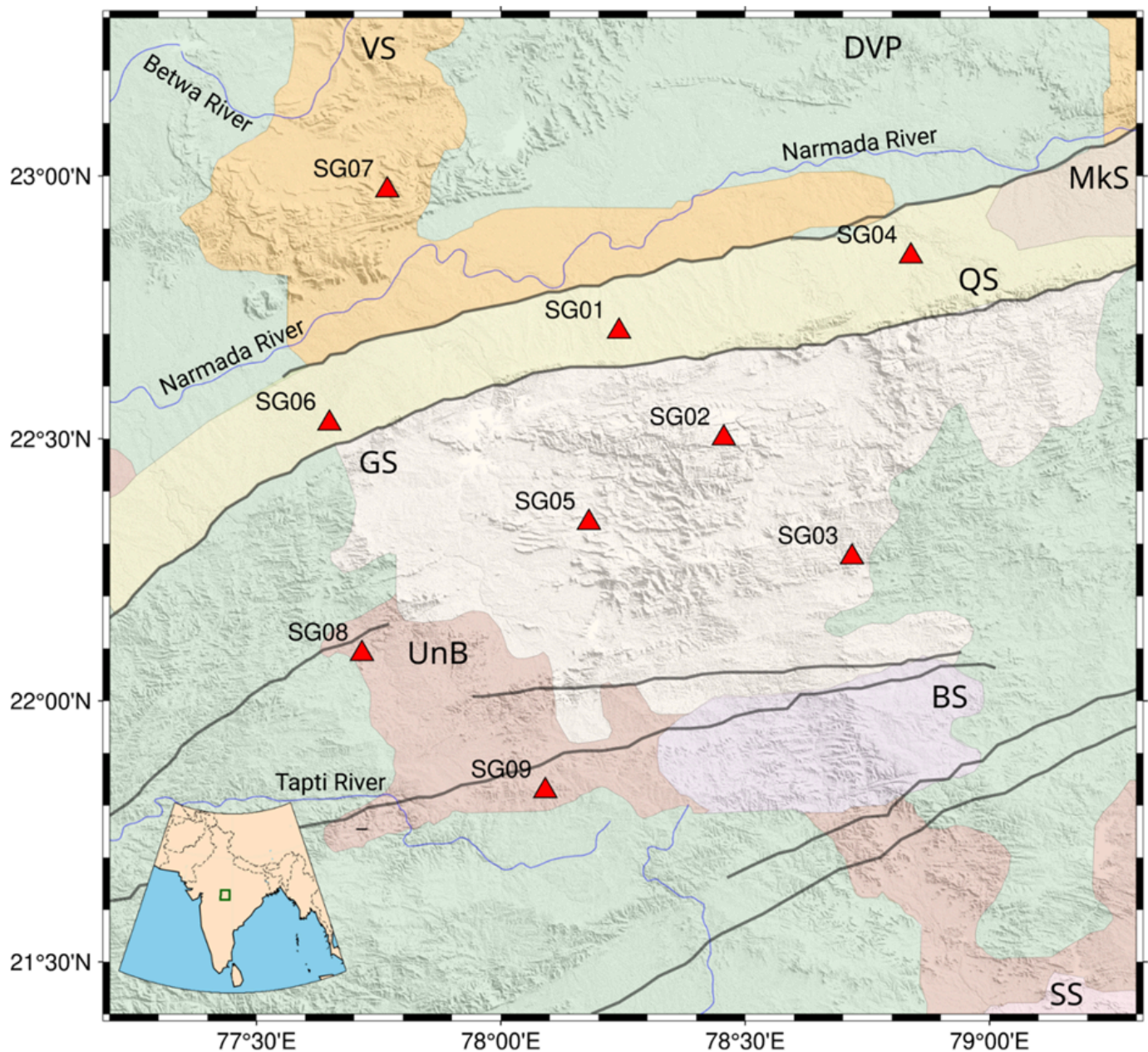


Figure 1

A generalized geological and tectonic map with the installed seismic stations (red triangles) of the study region. Blue lines on the map showing major rivers, including the Narmada River and its tributaries such as the Tawa, Denwa, and Ganjal rivers. Abbreviations used are VS for Vindhyan Supergroup, DVP for Deccan Volcanic Province, MkS for Mahakoshal Supracrustal, QS for Quaternary Sediments, GS for Gondwana Supergroup, UnB for Unclassified Basements, BS for Betul Supracrustal, and SS for Sauser Supracrustal.

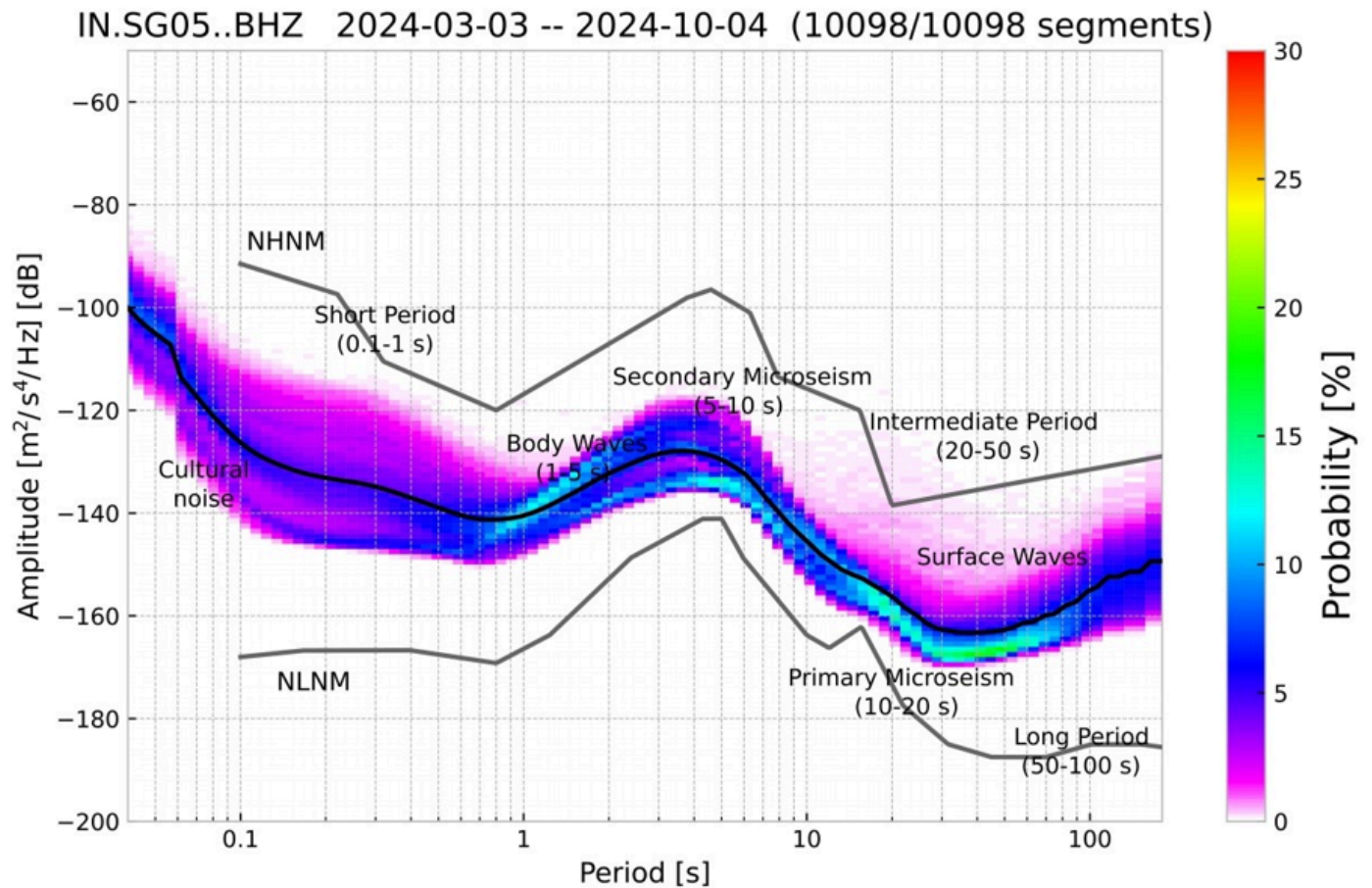


Figure 2

The PSD plot for station SG05 illustrates the variations in the noise spectrum across different period bands. The terms NHNM and NLNM refer to the new high noise model and the new low noise model, respectively. The colored bar indicates the probability of noise occurrence.

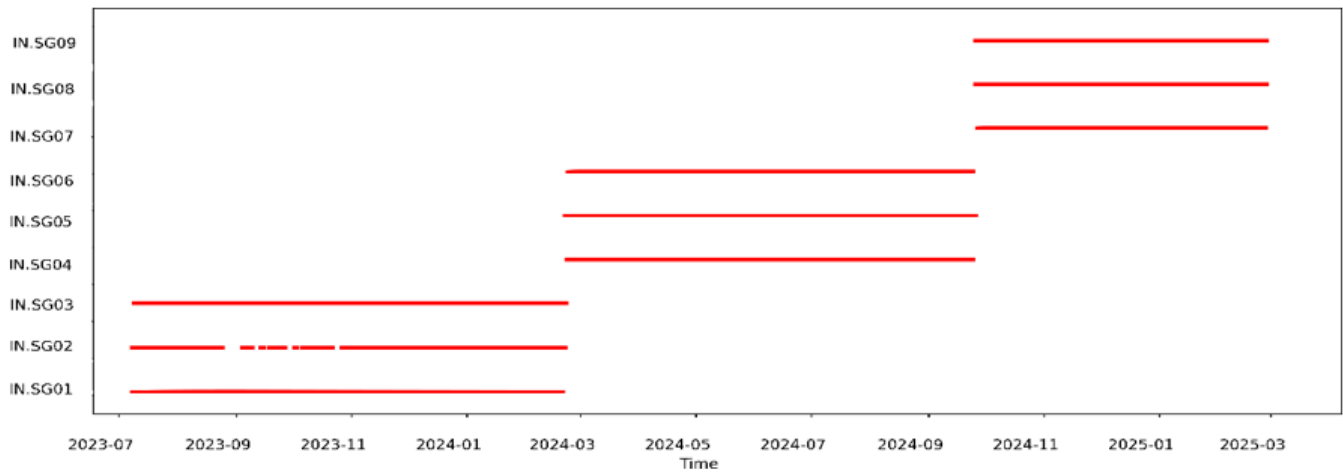


Figure 3

The illustration shows the data availability plot (station vs. time) for installed seismic stations that were operational from July 2023 to March 2025.

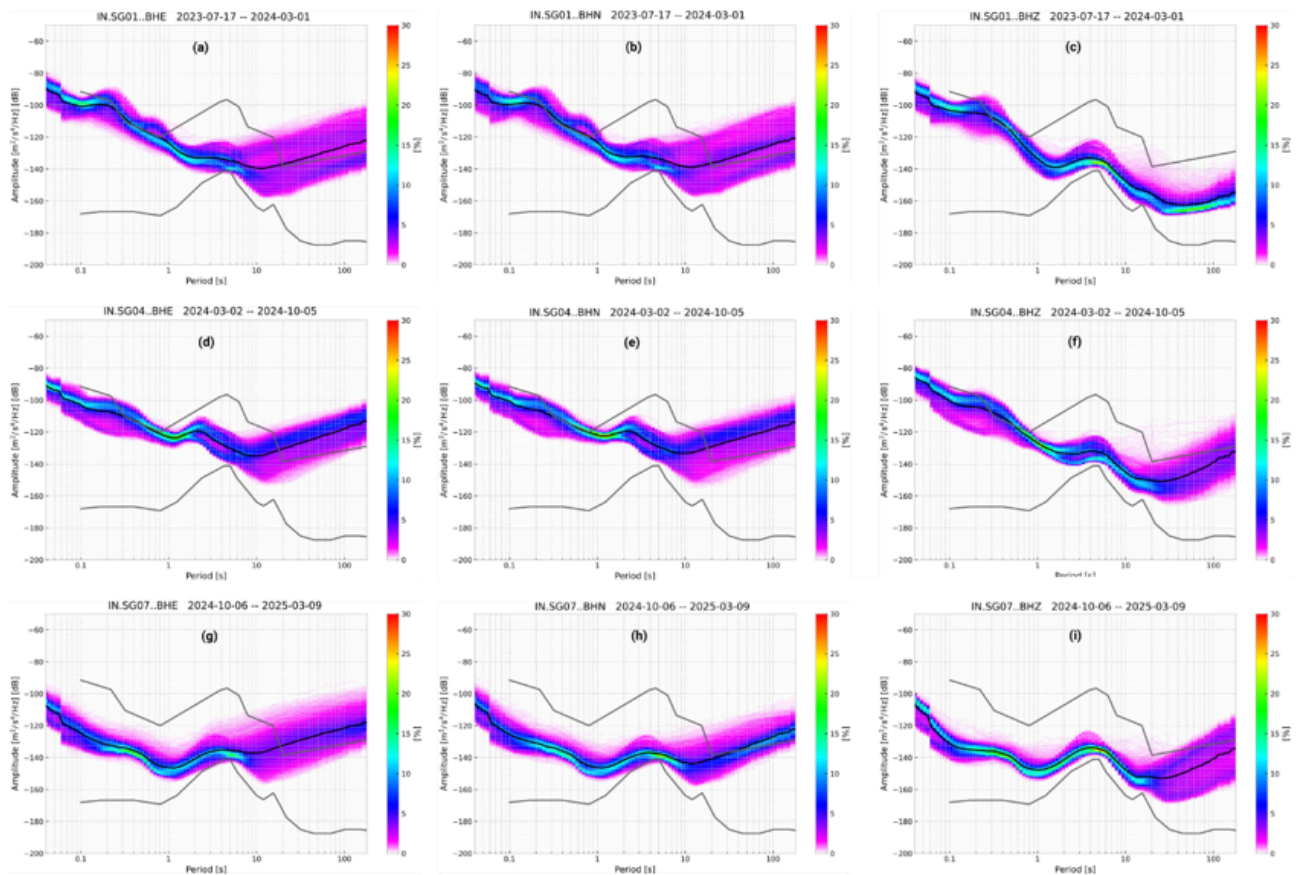


Figure 4

PSD plots for seismic stations SG01 (a-c), SG04 (d-f), and SG07 (g-i). Columns represent seismic components: East (a, d, g), North (b, e, h), and Vertical (c, f, i). The colored bar denotes the probability of noise occurrence.

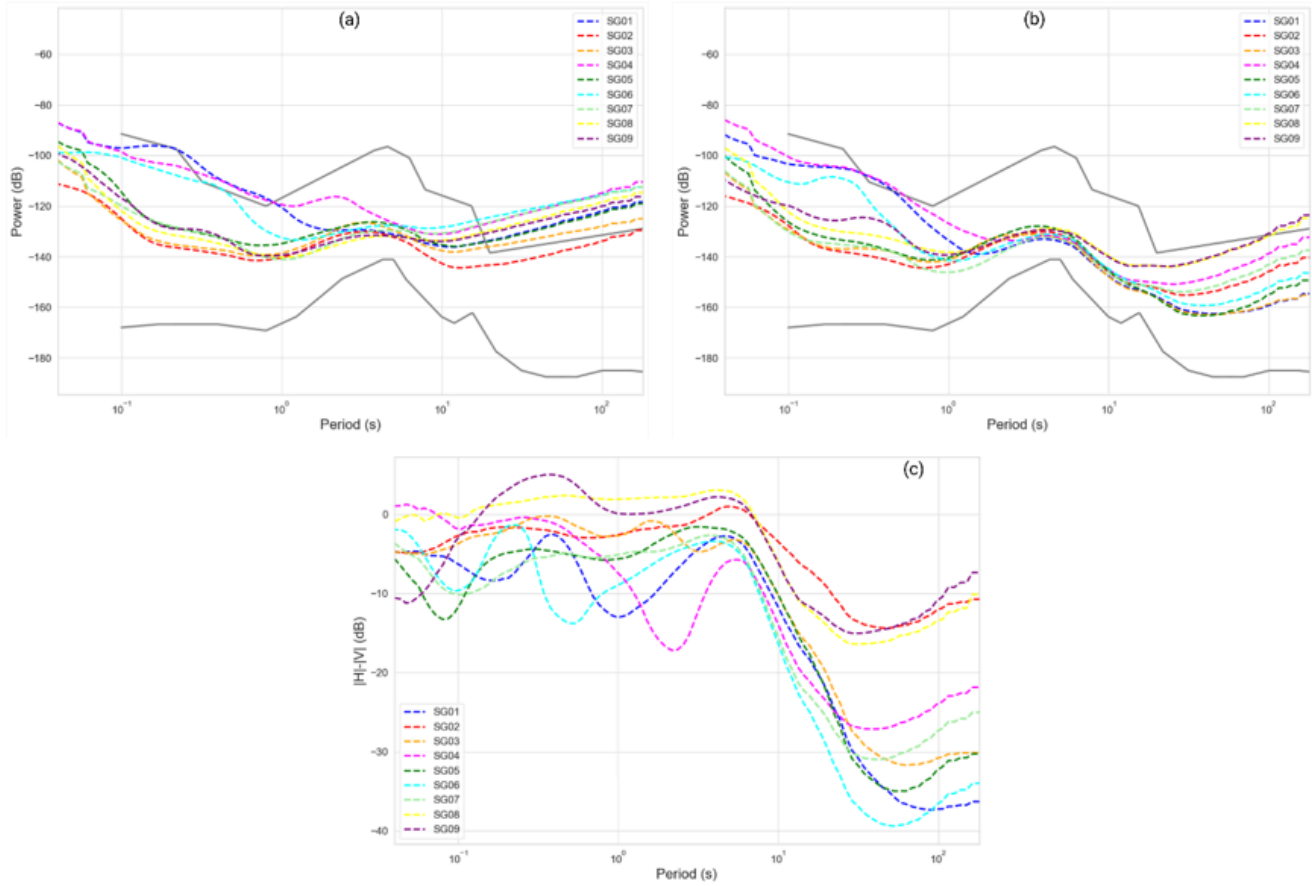


Figure 5

Median PSD plots of noise levels for (a) the horizontal component (H), (b) the vertical component (V), and (c) the H-V difference in decibels (dB) for all nine seismic stations.

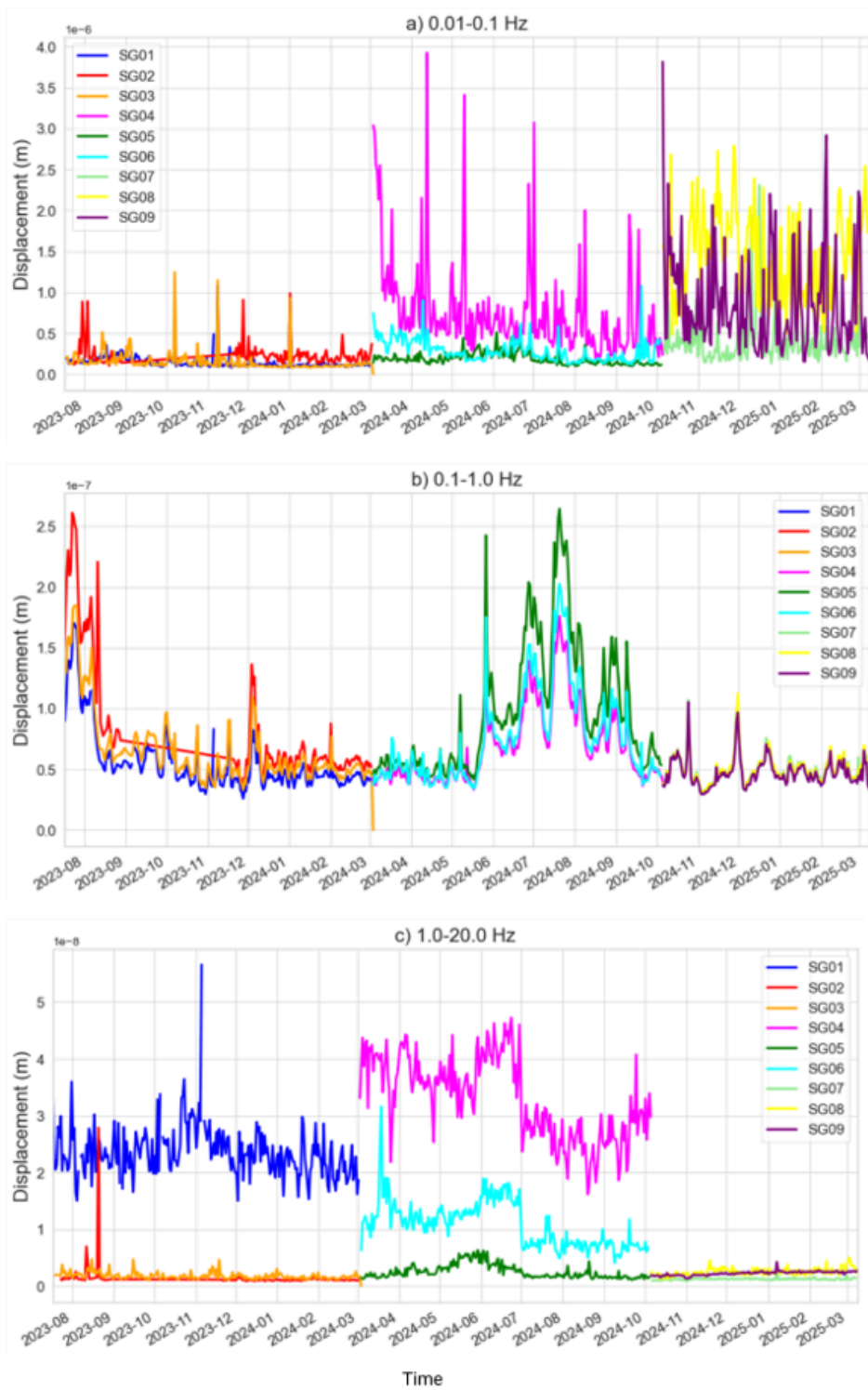


Figure 6

The temporal variation of the daily median RMS ground displacement amplitude at all stations in the frequency bands of (a) 0.01-0.1 Hz, (b) 0.1-1.0 Hz, and (c) 1.0-20.0 Hz.

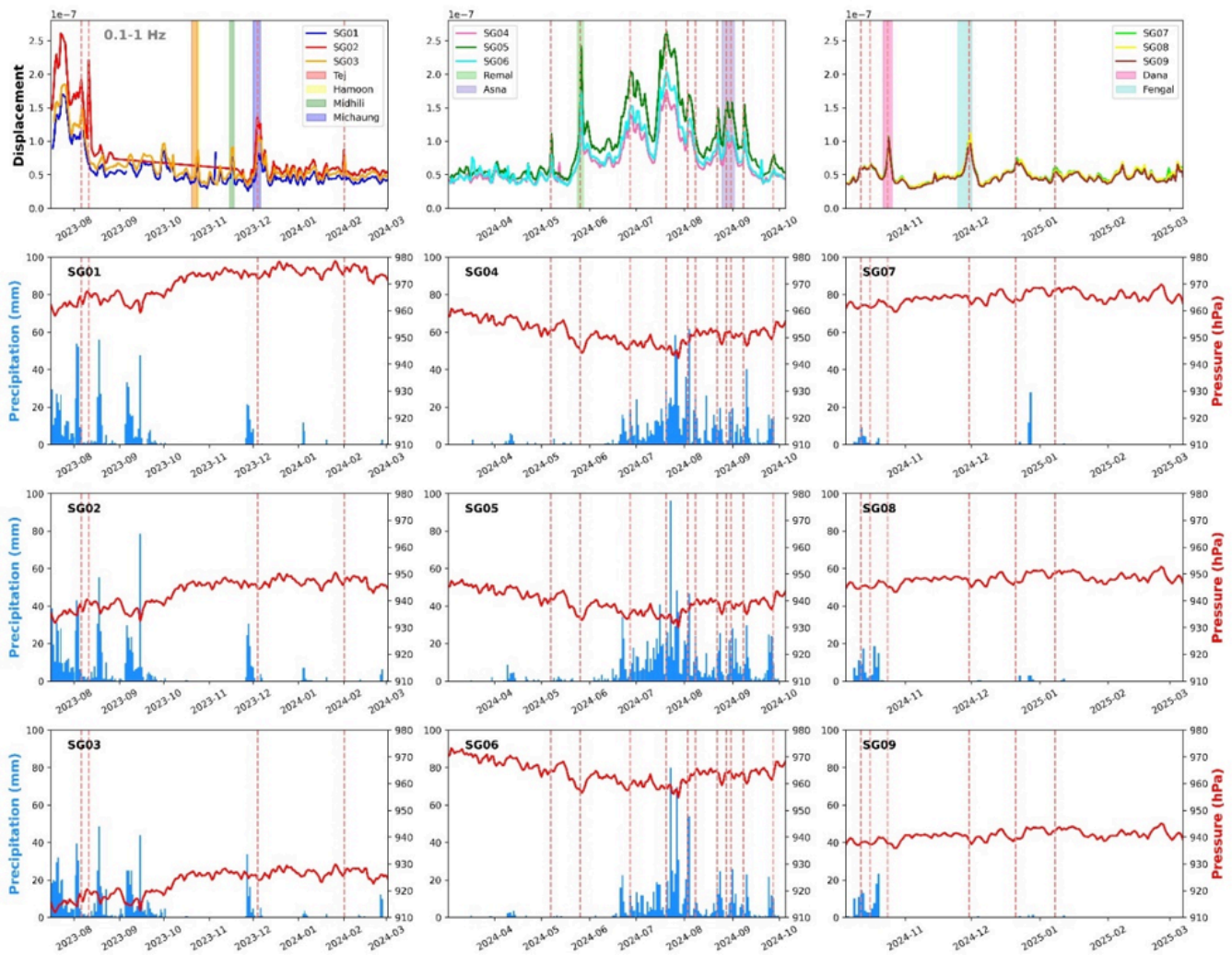


Figure 7

Correlation of temporal RMS ground displacement amplitude within the 0.1 - 1 Hz frequency range across nine seismic sites (SG01 to SG09) with daily cumulative precipitation (sky blue bars) and daily mean atmospheric surface pressure (red line). Precipitation and atmospheric pressure data were obtained from the ERA5 reanalysis dataset through the Copernicus Climate Data Store (C3S, 2024) at a spatial resolution of $0.25^\circ \times 0.25^\circ$. The pressure dataset represents the hourly data aggregated to the daily mean, while the precipitation dataset represents the hourly data aggregated to the daily sum. The ground displacement panel illustrates the timing of significant cyclones likely impacting the research area.

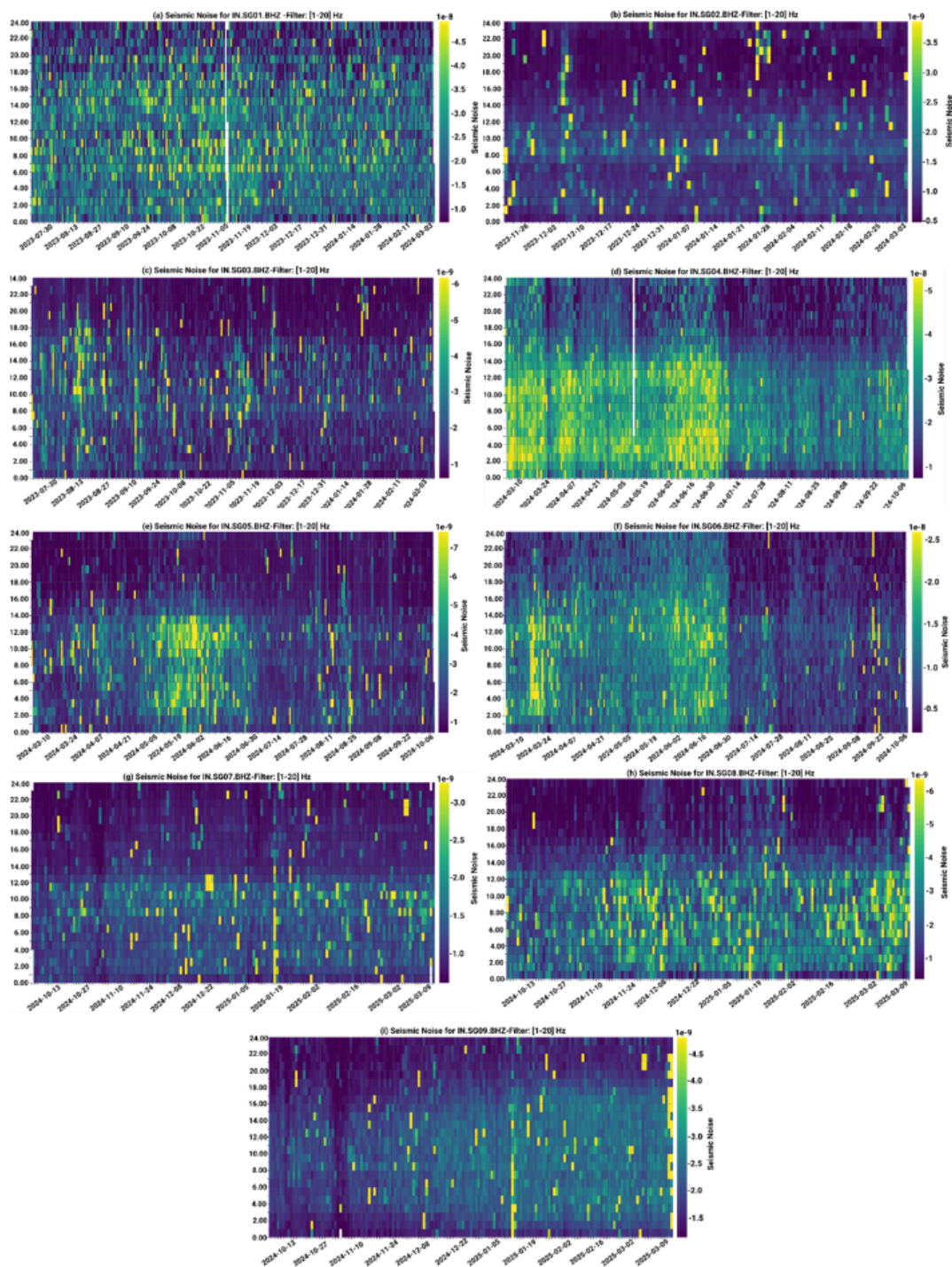


Figure 8

Temporal variation of seismic noise displacement on an hourly scale in the 1-20 Hz frequency range, with particular dates and times of day. The colored bar represents the probability density of ground displacement.

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