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Seismic Background Noise Evaluation at Saki Seismic Station, Oyo State, Nigeria

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ABSTRACT

Measures have been taken to densify the seismic monitoring stations in Nigeria to enhance and supplement the monitoring and recording capacities of the current monitoring stations in the country, since local earthquakes are becoming more frequent. A comprehensive background noise analysis is advised to achieve peak performance and enhance comprehension of the new station's representative seismic signal. Determining the background noise for the recently installed seismic station at Saki in Oyo State to ensure the reliability of the data is the goal of this study. Using a MATLAB package, PQL, and Seisan software, the approach involves the collection of noise data from the station and processing it to determine and identify the appropriate background noise. The raw waveforms were sorted, de-trended, and demeaned to remove instrumental errors and other unwanted trends. The Fast Fourier Transform was implemented to convert the time series into the frequency domain to understand the behavior of the background noise at different frequency bands. The results show that the background noise on the three components of the Saki seismic station (Vertical (Z), horizontal (E), and northing (N)) was low on both low and high frequency bands, indicating a good station with low background noise. The minimum and maximum amplitudes of the waveform and the number of counts also indicate a low background noise. The geology and location of the Saki seismic station may have contributed to the station's low-level and consistent background noise. The findings will assist in the comprehension of the potential background noise during the routine data processing, as well as serving as a benchmark for background noise analysis for future seismic stations in Nigeria.

Keywords:
Nigeria,
Seismic infrastructure,
Saki Seismic Stations,
Seismic Background noise.

INTRODUCTION

Seismic noise refers to the constant low-amplitude vibrations of the Earth's surface, which are crucial for seismic studies aimed at understanding the dynamic processes of our planet. According to a study by Bruce and Oliver (1959), the amplitude of these vibrations typically ranges from 0.1 to 10 μm/s, influenced by various physical and environmental factors. This ambient seismic noise includes vibrations from natural sources, such as ocean waves, as well as human activities like industrial operations and transportation.

Global analyses have evaluated different models of high and low background noise across various frequencies (Bensen et al., 2007). Oceanic gravity waves are the primary drivers of these ambient vibrations, generating pressure fluctuations that propagate into the Earth's crust and produce several categories of noise: seismic hum, primary microseisms, and secondary microseisms.

Seismic hum operates within the frequency range of 1 to 20 mHz and originates from large-scale atmospheric and oceanic processes. Primary microseisms, which occur between 0.02 and 0.1 Hz, are generated by ocean waves impacting coastlines and tend to be seasonal. In contrast, secondary microseisms, with frequencies ranging from 0.1 to 1 Hz, arise from the interaction of opposing ocean waves. Infragravity waves, with frequencies below 20 mHz, reach the abyssal floor, creating subtle pressure variations that can be detected within the Earth's crust.

Understanding seismic noise is crucial for differentiating between natural seismic events and ambient vibrations, which enhances earthquake monitoring and hazard assessment. Since Brune and Oliver (1959) developed high and low seismic background displacement curves based on a global assessment of station noise, earth noise models have become essential in seismic science. These models have established instrument specifications, assessed and compared station site characteristics, and predicted sensor responses to both calm and noisy background conditions.

The most common sources of seismic background noise, as identified by Bonnefoy-Claudet et al. (2006) and McNamara and Boaz (2019), include river discharge, tidal waves, storms, wind-induced tree and building movements, industrial machinery, moving vehicles, trains, and pedestrian footsteps. Each of these sources produces noise at specific frequency bands within the amplitude spectrum, which are typically independent of location, geological conditions, and time. Consequently, these sources can be categorized based on their frequency content (Bonnefoy-Claudet et al., 2006).

Seismic background noise data are primarily collected to evaluate the suitability of locations for temporary or long-term seismic recording setups. The quality requirements for these sites depend on the specific goals of the seismic observations and are influenced by various factors, including resolution, dynamic range, bandwidth, and frequency range (Bormann, 1998).

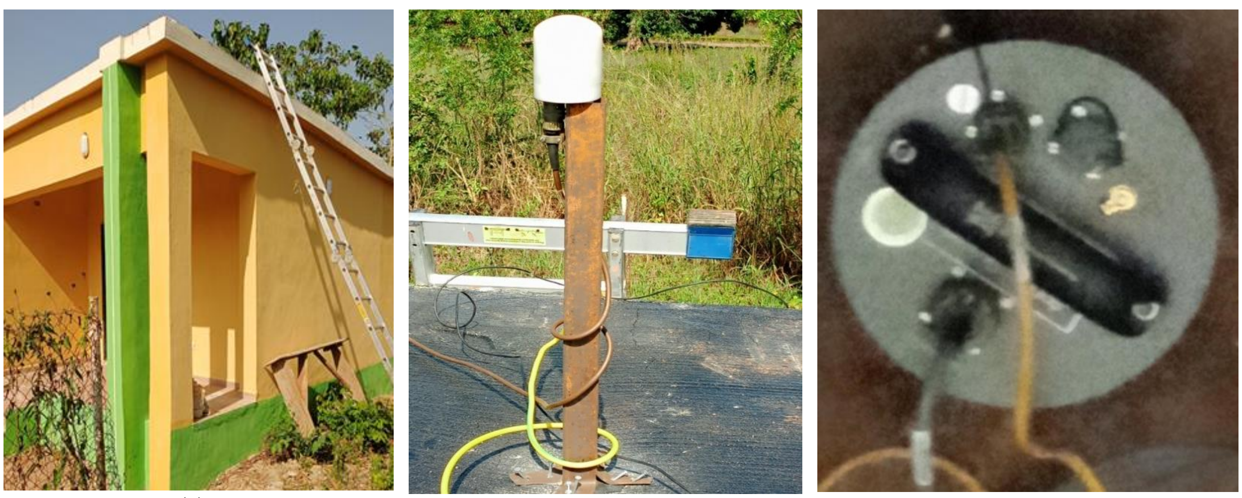
At low frequencies (less than 10^{-1} Hz), seismic noise mainly originates from natural sources, such as local weather patterns and oceanic disturbances. In particular, infragravity waves and microseisms induced by storms contribute to this noise. The microseism frequency range exhibits a global peak in noise amplitude around 0.2 Hz, which is influenced by seasonal ocean behavior and local weather events, such as monsoons. In contrast, at higher frequencies (greater than 1 Hz), human activities—such as traffic and industrial operations—serve as the primary sources of seismic noise, showing significant daily fluctuations in noise levels. Natural factors, such as wind, also contribute to broadband noise and long-period variations, especially in horizontal components, which are affected by wind strength (Burtin et al., 2008).

Seismic background noise varies significantly across different locations, with variations occurring in less than one second (Kadiri and Ezomo, 2013). This background noise has a cultural component on a continental scale. Day/night cycles help distinguish cultural noise from natural microseisms. A notable diurnal variation in background noise at a station may indicate the need to relocate short-period instruments to a more isolated site. This study aims to analyze the background noise at the Saki seismic station to assess data reliability. All figures and photographs referenced in this paper are included after the References section.

MATERIALS AND METHODS

Saki Seismic Station (Photos)

Figure 1 shows some installed infrastructure at the Saki Seismic Station in Oyo State, Nigeria. These include, but are not limited to, the building, seismometer vault, GPS Antenna, Short-period seismometer, etc.



(a) (b) (c)

Figure 1: (a) Seismic Station at Saki, Oyo State, Nigeria. (b) GPS Antenna at Saki Seismic station and (c) Short-period seismometer at Saki Station

Specifications of the Digital Seismometer Installed at Saki

Model: 6T-MAV101300242-CD24030U10163

Sensor Name: 6TD Guralp Digital Sensor

This advanced digital seismometer covers a period range from 30 seconds to 100 Hz, providing broad spectral sensitivity essential for high-resolution seismic monitoring. Its generator constant of 2400 V/ms^{-1} (two units of 1200 V/ms^{-1}) ensures highly responsive data capture. Equipped with 16 GB of flash memory and an IEEE1394 port, the seismometer offers robust data storage and transfer capabilities. The triaxial, broadband sensor is designed for medium-motion measurements, with an integrated 3-channel, 24-bit ADC digitizer, enabling accurate multicomponent seismic data collection.

For seamless data accessibility, the seismometer supports both WiFi and Ethernet connections. The instrument is housed in a durable, hard-anodized aluminum enclosure, engineered for low power consumption and lightweight design, making it ideal for rapid deployment in a variety of field environments.

Accessories

i. ACC-6T-CD03 6TD Accessory Pack includes the following components:
ii. Ethernet and Wi-Fi Break-out box with a 2 m integrated cable (19-way to Break-out box)
iii. GNSS (GPS) receiver with a 15 m cable (6-way to 6-way)
iv. 10 m power cable (10-way to Pig-tail)
v. 10 m data cable (6-way to D-type Serial)
vi. 10 m FireWire cable (6-way to FireWire plug)
vii. 10 m Ethernet cable (6-way to 8P8C Ethernet plug)
viii. Wi-Fi antenna
ix. 3 m network diagnostics cable (19-way to D-type Serial for data and Pig-tail for power)

This comprehensive accessory pack delivers critical connectivity and diagnostic tools, ensuring reliable and adaptable setup across diverse operational settings.

Geology of the Study Area, Saki

Figure 2 illustrates the location of the newly established seismic station in Saki. The site is on a foundation of Precambrian basement complex rocks, with possibly younger metasediments from the lower Paleozoic era. The area features five major rock units identified by Rahaman (1988): Migmatite-gneiss complex, slightly migmatised to unmigmatised paraschist and meta-igneous rocks, Charnokitic rocks, Older granite, and the unmetamorphosed dolerite dyke, the youngest unit.

In Saki, these rocks are widespread, forming prominent features like hills with fractures and joints. They primarily include migmatites, gneiss, and granites, which can have either gradational or sharp contacts, as noted by Kogbe (1989). The terrain includes both high and low-lying hills, with round boulders and flat surfaces in some areas.

The geological structure of the Saki region is characterized by micro-folds and observable micro-faulting. Narrow quartz veins, and, in some areas, wider ones, are commonly found within the rocks, with some of these veins exhibiting deformation that leads to folds and micro-faults. Additionally, minor rock intrusions, such as pegmatite, have also been documented.

Seismic data were acquired from the Saki Seismic Station, encompassing both quiet and noisy periods. The data were sorted, processed, and analyzed using Matlab, PQL, and Seisan software. The time series data were transformed into the frequency domain using the Fast Fourier Transform (FFT). Background noise was assessed using one-hour data segments for each of the sensor's three components (Z, N, and E), recorded in miniSEED format.

The background noise during quiet intervals at the station, outside the principal microseismic band (1-20 seconds), remained remarkably consistent throughout the analyzed periods. Key tasks in data collection included avoiding seismic events and other transient phenomena, as well as ensuring that sufficient time intervals were examined to guarantee consistency in the data records selected for final processing. The power spectral density was calculated following the method outlined by Bendat and Piersol (1971).

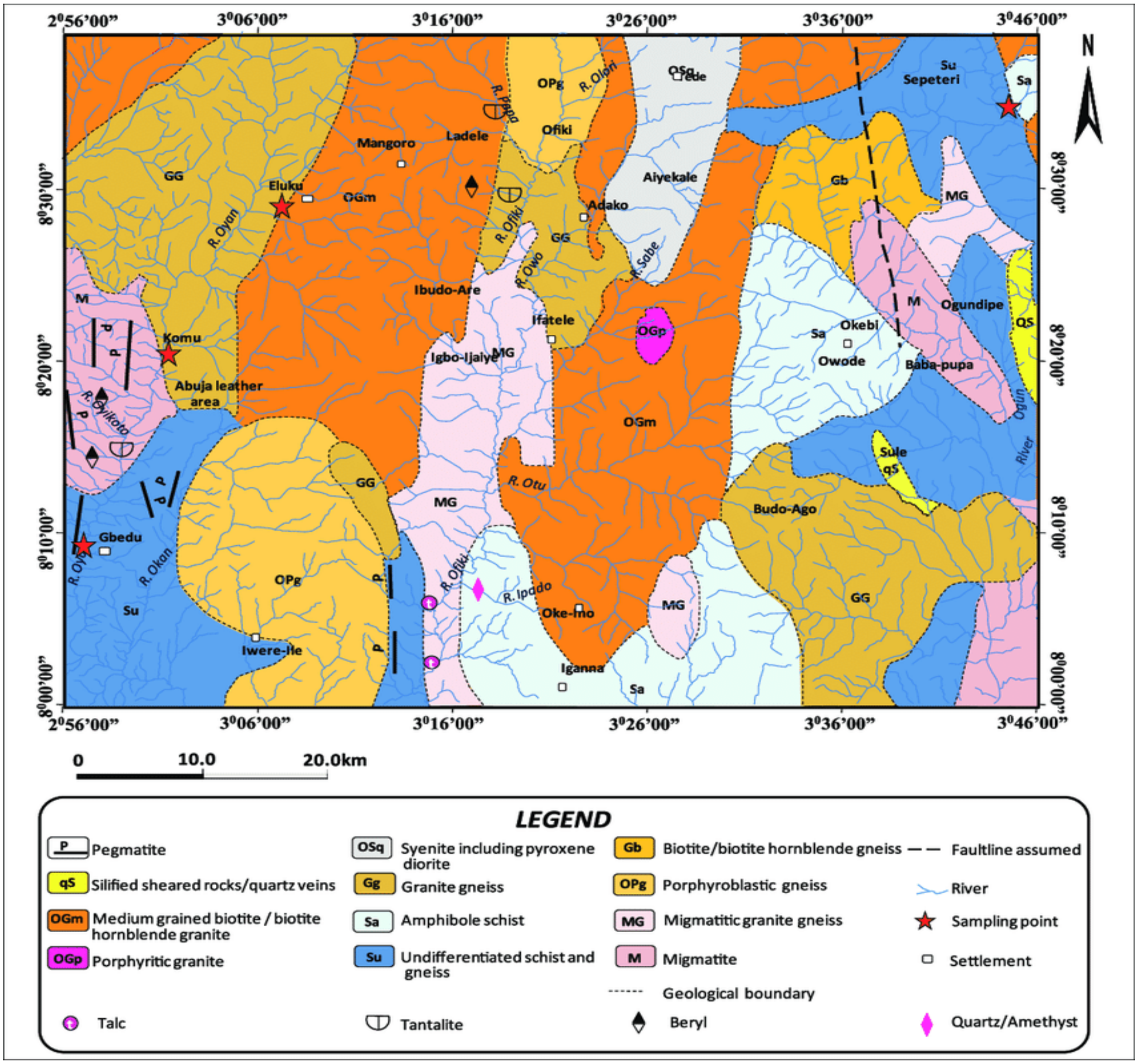


Figure 2: Geological map of Oke-Ogun, Saki, where the seismic station is located (after Ajetunmobi et al., 2019)

RESULTS AND DISCUSSION

The Power Spectral Density (PSD) and spectral overlays presented in this research provide insights into the structural characteristics of the Earth's vibrations as recorded at the Saki seismic station. These overlays emphasize dominant seismic features, particularly the natural microseisms that occur within a period range of approximately 1 to 20 seconds, with notable peaks at 5 seconds and 18 seconds. These microseisms are crucial indicators of oceanic and atmospheric activity that influence the Earth's crust. Furthermore, the overlays reveal Earth tidal patterns with peaks at semi-diurnal and diurnal periods, which are linked to the gravitational forces exerted by the moon and sun. This adds further structure to the Earth's noise spectrum. According to Bormann (1998), the appearance of noise in seismic records, in terms of both amplitude and frequency, exhibits significant variability, leading to corresponding differences in the derived noise spectra.

Although Bendat and Piersol (1971) used random data for their processing and analysis, the difference between this study and theirs is that Bendat and Piersol (1971) used non-continuous data. In contrast, we used continuous waveform data for seismic noise analysis using the same spectral technique. Similarly, Kadiri et al. (2028) conducted a preliminary evaluation of broadband seismic stations in Nigeria using the Pascal Quick Look X (PQLX), and FFT a MATLAB script. The main results obtained by Kadiri et al. (2018) were signal-to-noise ratio (SNR) values for the existing stations in Nigeria, along with the implementation of data from various research areas, such as Receiver Function. In this study, however,

we evaluated the background noise of the newly established seismic station at Saki with state-of-the-art equipment to understand noise characteristics and enhance knowledge of background noise at the station. This valuable information about background noise helps distinguish between natural and human-made events.
Figure 3 illustrates noise recordings across the three primary components of the seismic station at Saki: the vertical (Z), horizontal (E), and northing (N) components. During measurements, slight instability was noted in the E (horizontal) component, a common occurrence across different sensor types—including Short Period, Broad Band, and Accelerometers—often due to gravitational influences affecting horizontal orientations.
Instrumental spikes were also observed on the waveforms; these are artifacts that can result from sensor interactions or environmental influences. Despite these minor inconsistencies, the obtained noise waveforms are reliable and exhibit significant structural features that are valuable for analyzing seismic activity in the Saki area.

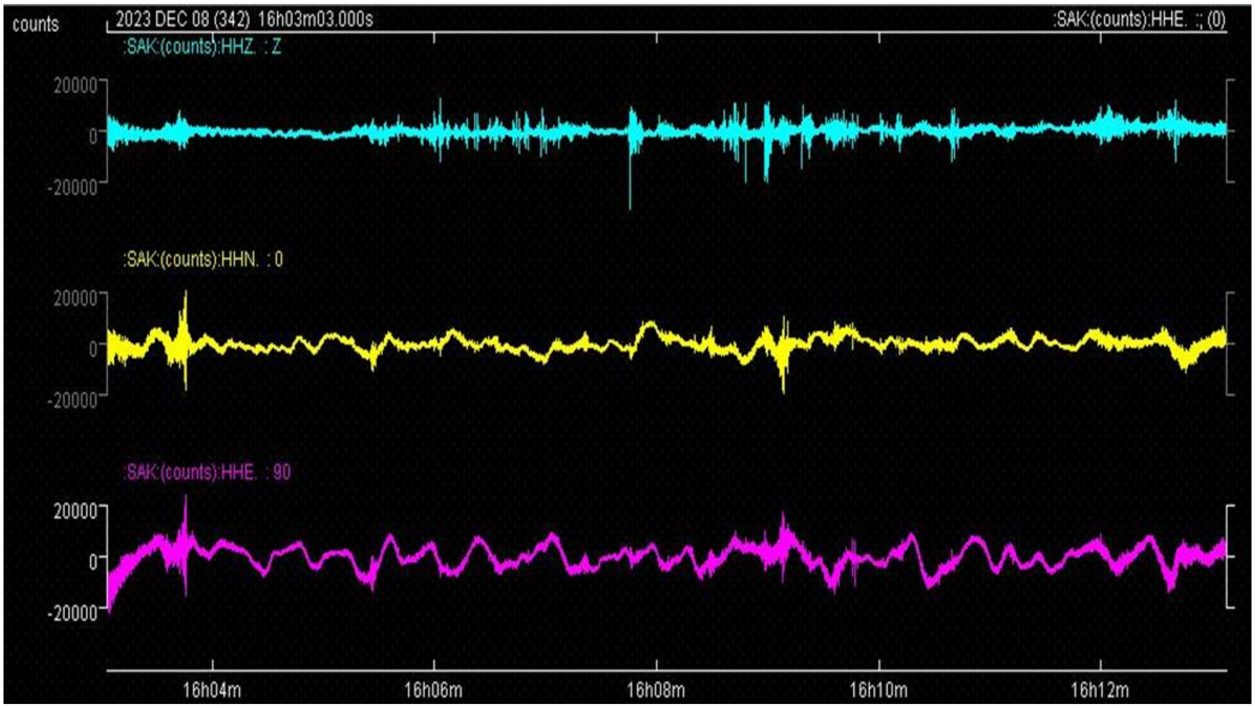


Figure 3: Raw wiggles of the three components (Z, N, and E) from Saki Station

Figure 4 illustrates the spectral decay pattern of the Z (vertical) component from the sensor at the Saki seismic station. It offers an in-depth view of the frequency-dependent behavior of Earth noise as recorded by the instrument. This decay pattern showcases distinct features that are essential for evaluating the station's performance and ambient noise levels. Notably, the graph emphasizes a specific section with spectral values ranging from approximately -3 to -1 Hz. In this range, the sensor's response is primarily influenced by its operational characteristics rather than by environmental signals. Understanding this range is crucial, as it helps establish the baseline sensitivity and effectiveness of the sensor in detecting seismic signals in the surrounding area.
Figure 5 shows significant microseismic peaks at frequencies around 0 Hz and 1 Hz. These peaks represent the energy associated with low-frequency ambient seismic noise, primarily generated by natural processes such as ocean waves interacting with the Earth's crust. The presence and strength of these microseismic peaks indicate the level of natural background noise, and their visibility on the spectral decay curve suggests that the station is functioning well.
The clarity with which these features can be observed implies that the Saki station is effectively isolated from excessive human-made noise sources, maintaining a low level of background noise that is essential for accurately detecting and analyzing seismic activity. This quality of low ambient noise is crucial for reliable data collection, as it enables the station to pick up subtle seismic events while minimizing interference. This enhances the station's overall effectiveness in monitoring regional tectonic and environmental processes.

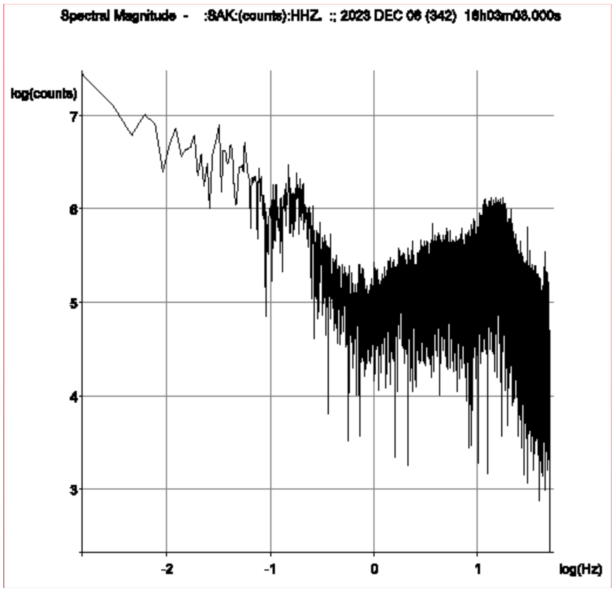


Figure 4: Spectral decay of Z component

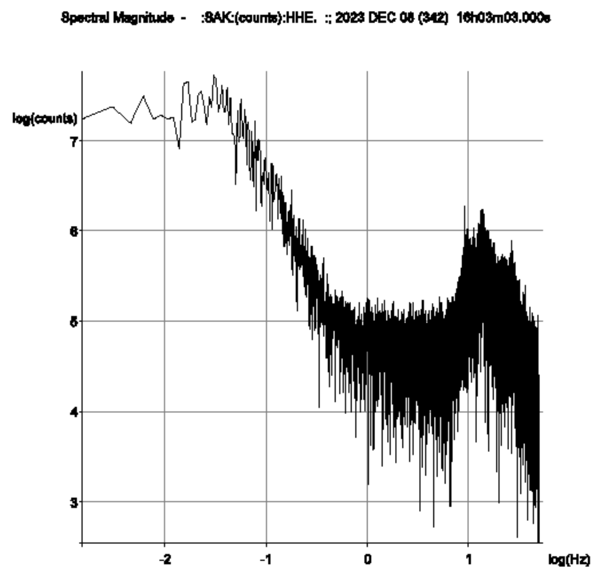


Figure 5: Spectral decay of Z component

Figure 6 provides an analysis of the spectral decay for the E (horizontal) component of the sensor at the Saki seismic station, highlighting specific frequency characteristics that offer valuable insight into the station's operation and sensitivity to ambient noise. The decay graph showcases a distinct instrumental region within the range of -3 to -1 Hz, where the sensor's own mechanisms, rather than external environmental factors, are the primary contributors to the recorded signal. This instrumental band is crucial for determining the baseline behavior of the E component, allowing researchers to assess the stability and accuracy of the sensor in detecting external seismic events. Additionally, prominent microseismic peaks at approximately 0 Hz and 1 Hz are visible, representing low-frequency oscillations tied to natural forces like oceanic wave impacts on the Earth's surface. These peaks serve as indicators of natural background seismic energy, and their distinct presence in the spectral decay pattern reflects a low-noise environment around the Saki station, further supporting the station's high-quality recording capabilities.

In Figure 7, key properties of the short-period sensor used at the Saki seismic station are presented, along with critical configuration values that define the sensor's operational parameters. This includes the sampling rate, which determines the frequency at which the sensor records seismic data, ensuring the capture of both low- and high-frequency signals. The start date of the station's operations is also documented, offering a historical reference for data collection and system monitoring over time. Additionally, other configuration values relevant to the sensor's calibration and performance are highlighted, ensuring that the setup is optimized for capturing accurate seismic readings. Together, these configuration details and sensor properties illustrate the robustness of the Saki station's setup, confirming that it is well-equipped to conduct reliable seismic monitoring with minimal interference from background noise.

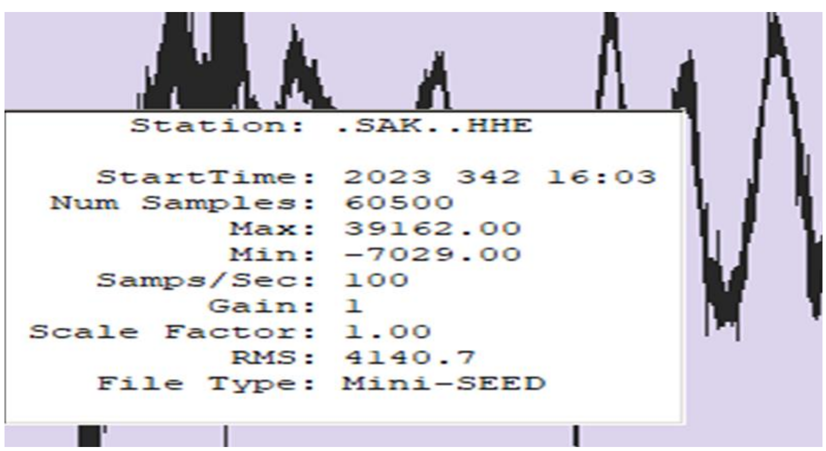


Figure 6: Properties of the sensor at Saki and configuration values

Figure 7 presents an enlarged view of the noise trace recorded on the E (horizontal) component of the Saki seismic sensor, providing a closer look at the sensor's raw output. This trace displays the waveform in its initial form, capturing ambient noise signals as detected by the sensor before any major processing. Notably, the waveform has already undergone detrending and demeaning, essential preprocessing steps that remove linear trends and mean values, respectively, to produce a cleaner baseline. These adjustments enhance the clarity of the signal by reducing low-frequency drift and offset, allowing for a more accurate interpretation of the seismic noise characteristics in the Saki region.

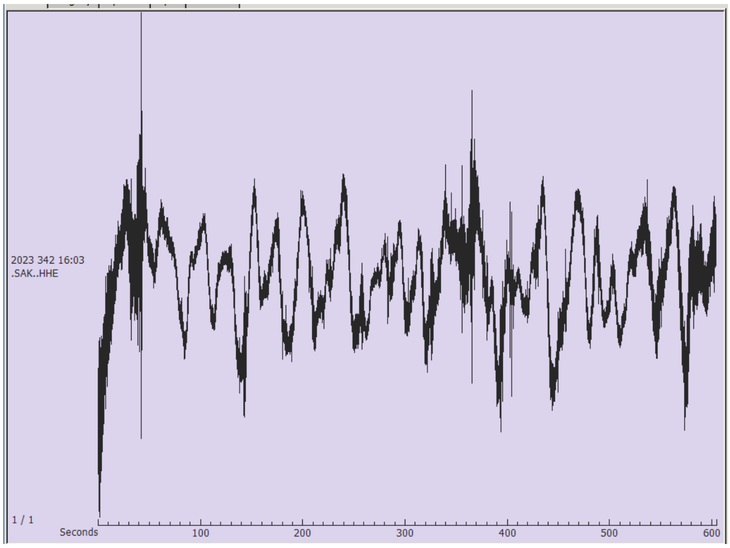


Figure 7: Enlarged noise trace from Saki

Figure 8 presents a split noise trace of the Z (vertical) component of the Saki seismic sensor, providing an in-depth look at the raw waveform data collected by the instrument. This waveform has already undergone detrending and demeaning, essential preprocessing techniques that remove linear trends and mean shifts to produce a more stable baseline. The trace reveals both minimum and maximum amplitude levels, along with the count of signal occurrences, offering insights into the sensor's sensitivity and noise profile. The low amplitude range and count values observed in the waveform indicate that the Saki station maintains low background noise, confirming the station's suitability for detecting subtle seismic activity without significant interference.

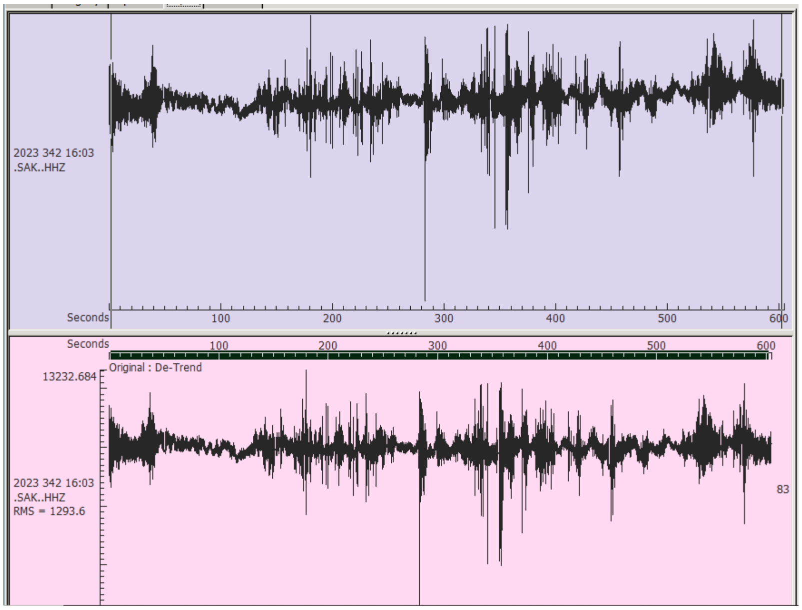


Figure 8: Split Z-component noise recordings

Figures 9 through 11 provide a detailed representation of the background noise observed across the E, N, and Z components of the short-period sensor at the Saki seismic station. These figures highlight the ambient noise levels recorded on each of the three components, which show consistently low noise levels, indicative of a high-quality seismic monitoring environment. The low noise levels observed across all components suggest that the station is operating in an optimal setting with minimal interference from external sources, thereby ensuring the accuracy and reliability of the data collected. These observations are crucial for validating the station's capability to detect subtle seismic events, as low background noise reduces the potential for misinterpretation of seismic signals.

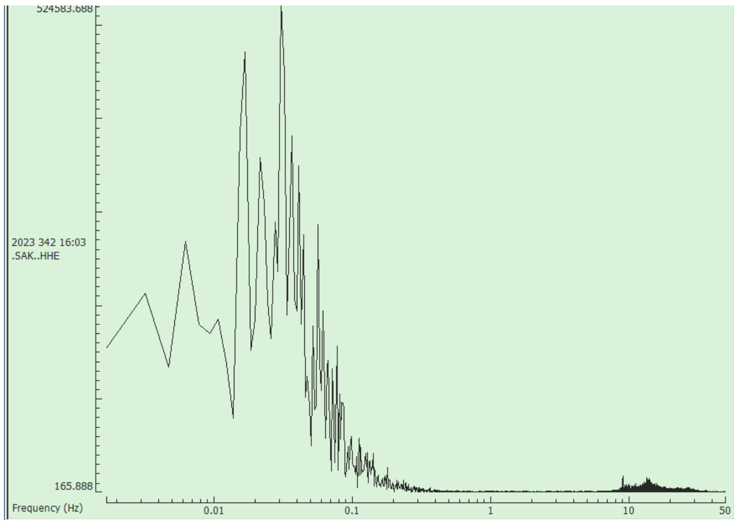


Figure 9: Background noise on the E component of the Sensor at Saki

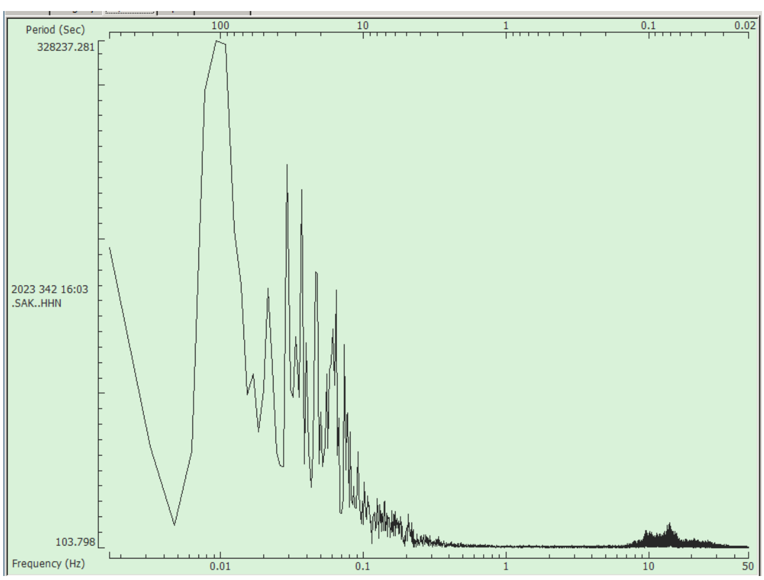


Figure 10: Background noise on the N component of the Sensor at Saki

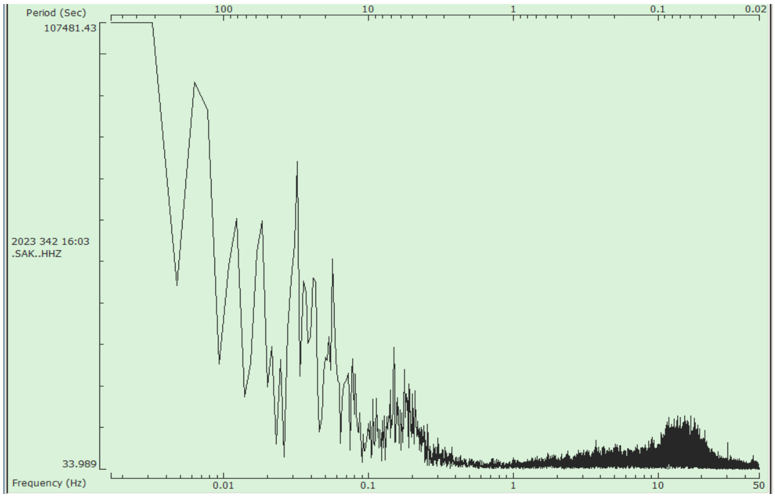


Figure 11: Background noise on the Z component of the Sensor at Saki

Figure 12 further supports these findings by showing an overlay of both high and low-frequency noise on the Z component, demonstrating the effective isolation of the station from significant sources of ambient noise. Overall, the consistently low noise levels across all components, as shown in these figures, reinforce the high-quality data acquisition capabilities of the Saki seismic station.

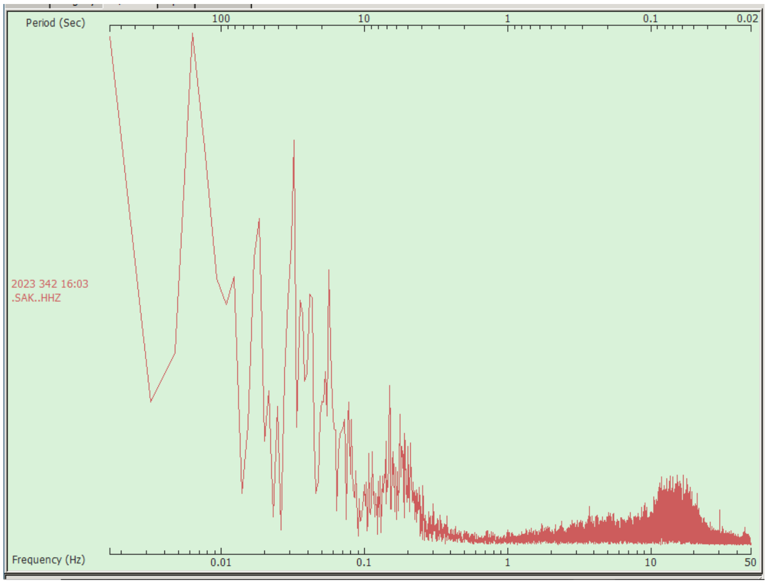


Figure 12: Overlay of background noise on the Z component of the Sensor at Saki (Single component)

Figure 13 displays a split trace and overlay of background noise on the Z (vertical) component of the seismic sensor at the Akure station, which operates with a single component. This visualization provides a clear representation of the ambient noise profile as captured by the Z component, highlighting the sensor's background noise levels. The Fourier transform applied to the time series reveals a predominance of low-amplitude background noise frequencies, indicating minimal interference from external sources and an effective environment for seismic monitoring.

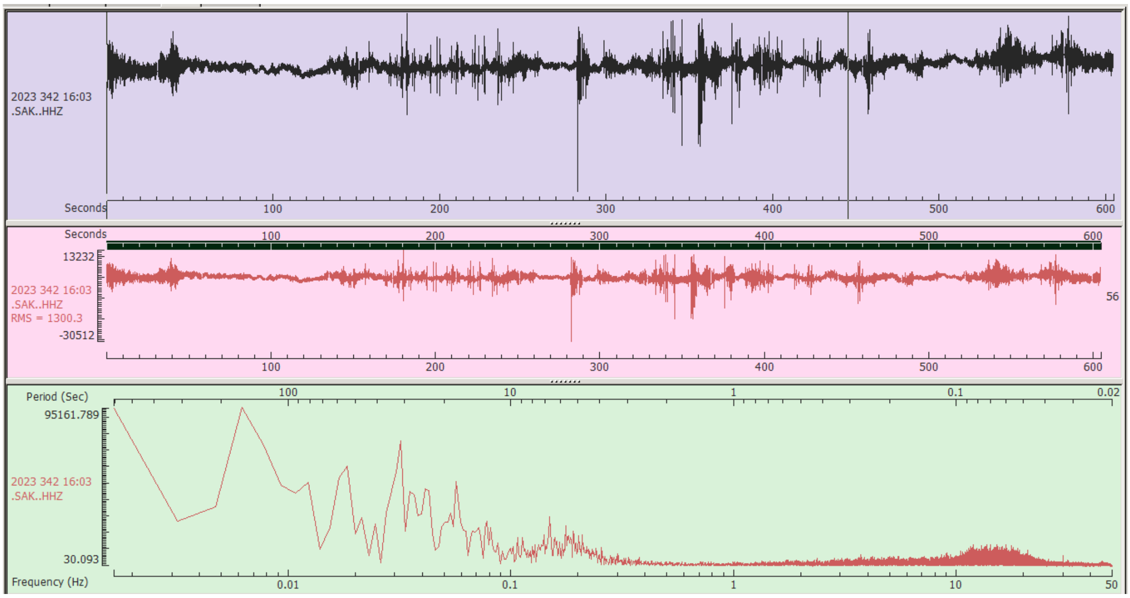


Figure 13: Split trace and overlay of background noise on the Z component of the Sensor at Saki (Single component)

Figure 14 shows the background noise on the Sensor's three components of Z, E, and N at Saki. The background noise levels on the respective components are low. Figure 15 is an overlay of the three components showing reasonably low background noise as well as at frequency 0.1-1.0Hz. The cultural noise (>1.0Hz) is also reasonably low.

The geology and location of the Saki station may have contributed to the low-level and consistent background noise at the Saki station. With the knowledge of the background noise, therefore, it would be easy to infer prospective high amplitude and low frequency disturbances on the seismograms from the station. It is, therefore, very important to understand the background noise of a seismic station to effectively and efficiently discriminate natural and anthropogenic signals.

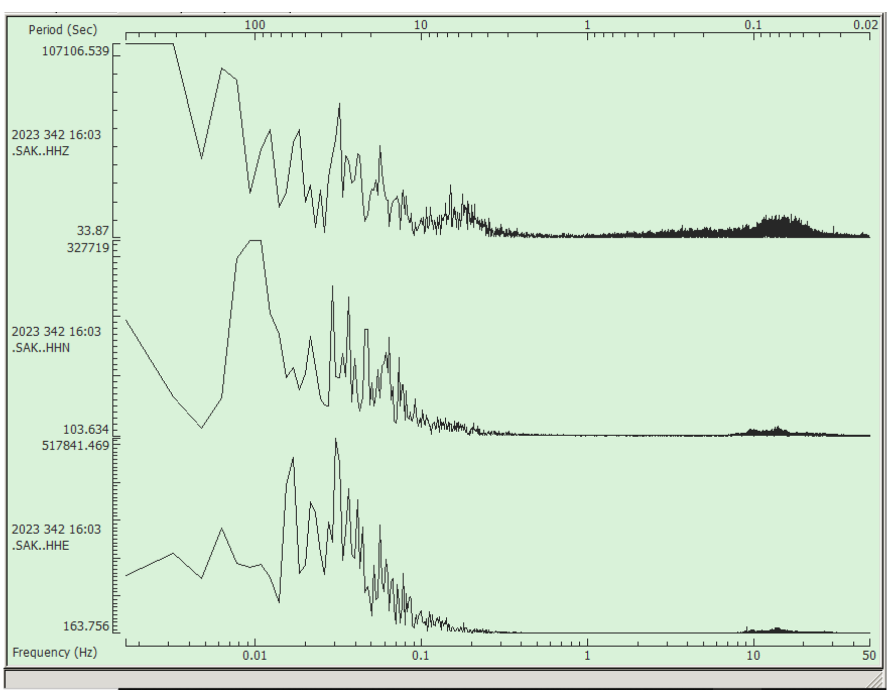


Figure 14: Background noise on the Z, E, and N components of the Sensor at Saki

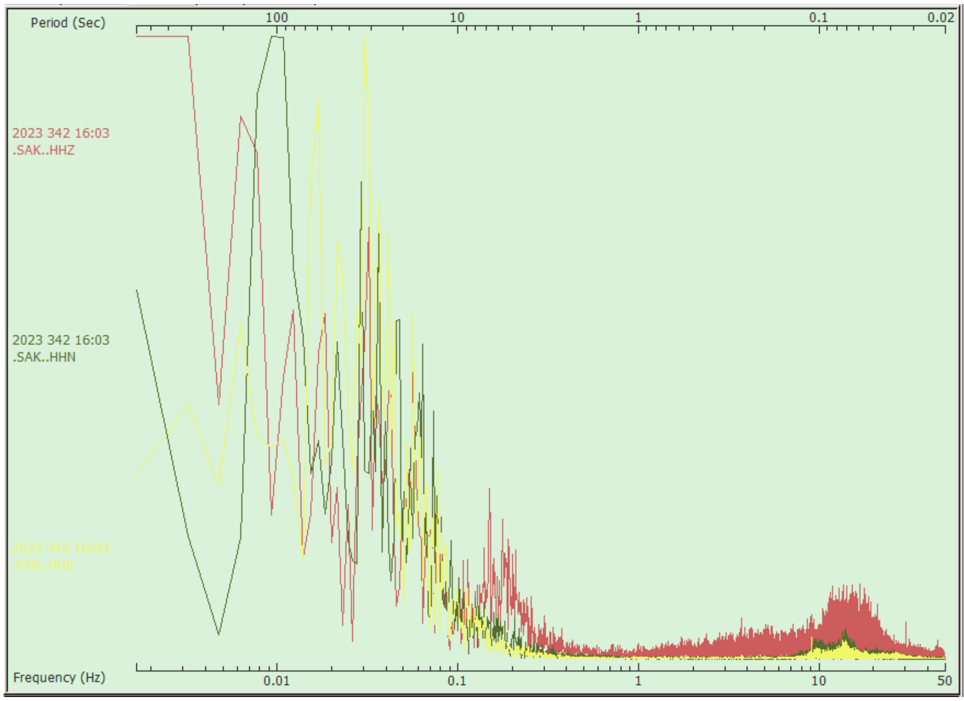


Figure 15: Overlay of the three components of the Short Period Sensor at Saki

Geology and Location Contribution to Low-Level Background Noise: The Saki seismic station benefits from its location and geological features, which help maintain low background noise levels. The area's geology includes granites, gneiss, and migmatites, whose fractured structures reduce ambient noise by dampening seismic wave transmission. Micro-folds in the rock formations also enhance this effect by absorbing or diverting vibrations. Additionally, the station is strategically placed in a region with minimal human activity, reducing interference from industrial operations and traffic. This optimal setting allows for accurate recording of seismic signals, improving the detection of minor seismic activity and the overall quality of data collected.

CONCLUSION

The background noise of the new seismic station located in Saki, Oyo state, has been evaluated. The background noise is generally low on the three components of the short-period sensor that was installed in December 2023. The Saki seismic station's low-level background noise was evaluated using sophisticated software tools for data processing, and the station's location site, which is far away from busy highways, human settlements, etc., as well as the geological features, likely contributed to the good background noise. Ultimately, the results highlight how important geological features and the station's location are in determining the background noise characteristics. This emphasizes the necessity of ongoing monitoring, teamwork in research, and improved data quality and ease of data processing and analysis, and enhancement of seismic monitoring capabilities at the Saki seismic station. With the background noise knowledge from this work, it would be easy to infer high amplitude and low-frequency disturbances on the seismograms from the station. It is, therefore, very important to understand the background noise of a seismic station to effectively and efficiently discriminate natural and anthropogenic signals and determine instrumental malfunctioning, with data quality as the ultimate goal.

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