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Evaluation of performance of z-component of Nigerian seismographic stations from spectral analysis

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Preliminary noise analysis has been carried out on the Z-components of the Nigerian National Network of Seismographic Stations (NNNSS) using data collected from the five operational stations (Toro, Kaduna, Nsukka, Awka and Ife) in 2012. The results of the analysis from noise spectra using SEISAN software clearly showed that the noise levels at the respective stations are high and the average noise levels are above the high noise model of Peterson curves. The possible sources of noise are cultural, actual earth vibrations and instrumentation. The study is intended to quantify the amount of noise present in the existing NNNSS and compare with Peterson noise curves, and understand the noise characteristics in order to adopt better practices in the day-to-day seismic stations' operations in Nigeria.

Key words: National network of seismographic stations (NNNSS), noise, spectral analysis, signal to noise ratio.

INTRODUCTION

In seismology and other fields that deal with signal, regarding noise as an undesirable component of the signal. Conventionally, noise is described as a disturbance in the signal which does not represent part of a message from a specified source (Sherrif, 1991).

Seismologists collect data on seismic background noise for assessing the suitability of sites for temporary or permanent seismic recordings. The stations that form the National Network of Seismographic Stations (NNNSS) are permanent seismic stations and installed with broadband seismometers. Site quality requirements depend on the task of seismic observations on their resolution, dynamic range, bandwidth and frequency range (Bormann, 1998). Till now, noise data are collected with a wide range of instruments, both analog and digital of different bandwidth, resolution and transfer functions. Accordingly, noise appearance in seismic records, amplitude- and frequency-wise, differs and the various kinds of noise spectra derived there vary too (Alguacil and Havskov, 2010). Apart from the noise spectra adopted in this study, another possible way to investigate noise level of a seismic station is to obtain velocity power spectra of ambient seismic noise at noisy and quiet conditions for each station based on their different geological setting (Aki and Richards, 1980) and when the frequency spectrum of the seismic signal of interest differs significantly from that of the superposed seismic noise, band-pass filtering can help to improve the signal-to-noise ratio (SNR) (Bormann, 2009 NMSOP). The velocity power spectra of ambient seismic noise and different ways of improving Signal to Noise Ratio (SNR) are not the purpose for this study.

Recorded seismic signals always contain noise and it is important to be aware of both the source of the noise

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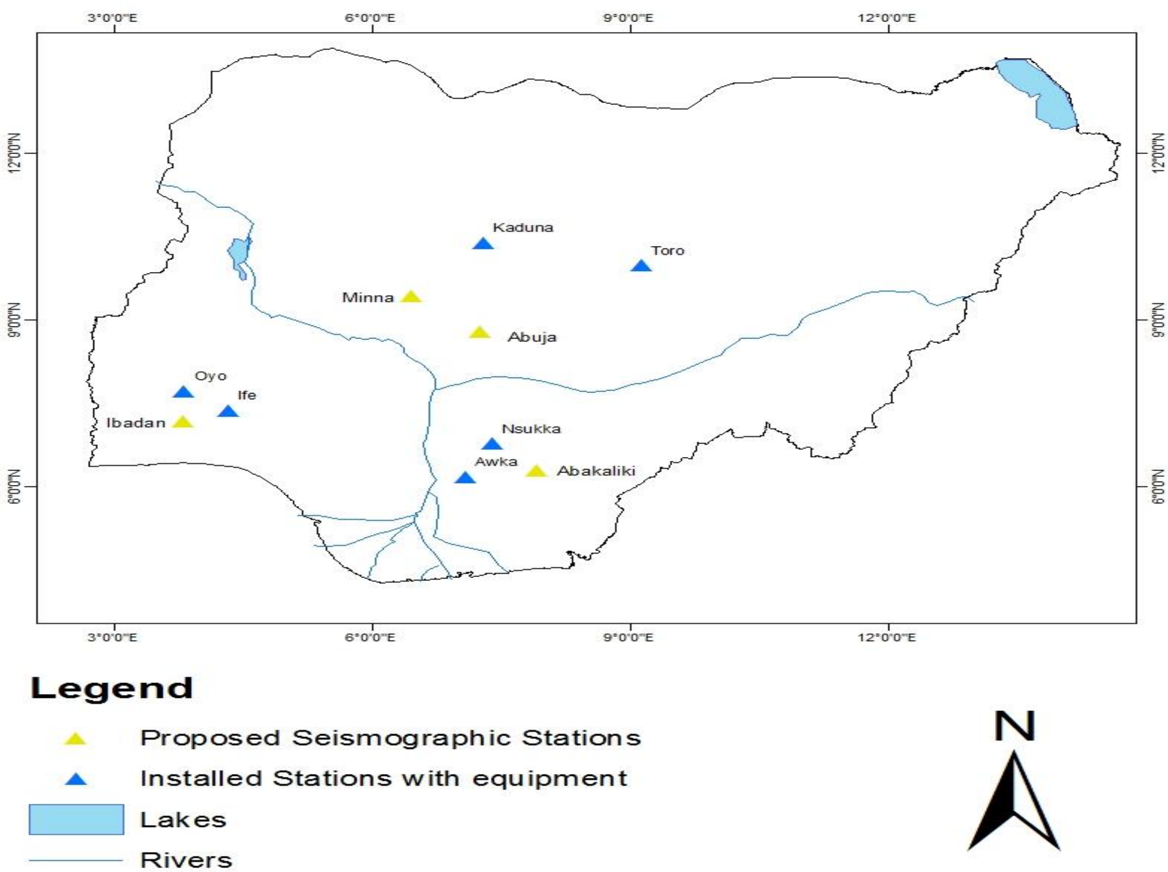

Figure 1. Map of Nigeria showing locations of existing and planned stations.

and how to measure it (Alguacil and Havskcov, 2010). Noise can have two origins: Noise generated in the instrumentation and 'real' seismic noise from earth vibrations. Normally, the instrument noise is well below the seismic noise although most sensors will have some frequency band where the instrumental noise is dominating (e.g. an accelerometer at low frequencies) (Havskov and Ottemoller, 2008).

Ambient seismic noise defines vibrations of the ground caused by sources such as tides, water waves striking the coast, turbulent wind, effects of wind on trees or buildings, traffic or human based noise (Bonnefoy-Claudet et al., 2006). Ambient seismic noise basically has two different origins-cultural and natural representing the microtremors and microseisms, respectively (Alguacil and Havscov, 2010). Origins of microtremors are mainly cultural from the actions of human beings. Other sources are rain, traffic, wind, industrial noise in the urban areas, geologic noise. Cultural noise are seen as high frequency noise surface waves greater than 1.0 Hz and attenuate within several kilometers in distance and depth (Alguacil and Havskcov, 2010). So it has strong significant lower noise levels in boreholes and deep tunnels. The noise at low frequency is typically higher on the horizontal component than on the vertical component due to the difficulty of stabilizing the station for small tilts and noise level vary greatly between different sites and different frequencies (Alguacil and Havskcov, 2010).

The Peterson (1993) noise curves and noise spectral level (Figure 5) has been used to evaluate noise levels for the IRIS station BOCO. Seismic noise at the station BNG (Bangui, Central Africa) had been evaluated (Bormann, 2009) and compared to the new global seismic noise model by the Peterson (1963) noise curves. Variations of seismic background noise in South Korea have been investigated using power spectral analysis (Sheen et al., 2009). These so-called Peterson curves (Figure 5) have become the standard, by which the noise levels at seismic stations are evaluated. The curves of Figure 5 represent upper and lower bounds of a cumulative compilation of representative ground acceleration power spectral densities determined for noisy and quiet periods at 75 worldwide distributed digital stations (Havskov and Ottemoller, 2008).

The Centre for Geodesy and Geodynamics (CGG) has been operating the NNNSS located in triangulations (Figure 1) across Nigeria. The properties of the respective stations are shown in Table 1. Other

Table 1. Location of NNNSS (Modified after Akpan and Yakubu, 2010).

S/N	Station name	Latitude	Longitude	Elevation (m)	Geologic foundation	Instrumentation
1	Oyo	07°53.131'N	03°57.078'E	295	Granite	Seismograph: DR4000 recorder Seismometer: SP400 medium period seismometer
2	Ibadan	07°27.251'N	03°53.520'E	193	Gneiss	No instrument installed
3	Ile-Ife	07°32.800'N	04°32.815'E	289	Gneiss	Seismograph: DR4000 recorder Seismometer: EP105 broadband seismometer
4	Awka	06°14.561'N	07°06.693'E	50	Shale and siltstone	No instrument installed
5	Nsukka	06°52.011'N	07°25.045'E	430	Sandstone	Seismograph: DR4000 recorder Seismometer: EP105 broadband seismometer
6	Abakiliki	06°23.453'N	08°01.474'E	82	Sandstone	No instrument installed
7	Abuja	08°59.126'N	07°23.380'E	432	Granite	No instrument installed
8	Toro (Central)	10°03.303N	09°07.089'E	882	Gneiss	No instrument installed
9	Kaduna	10°26.101'N	07°38.484'E	668	Granite	Seismograph: DR4000 recorder Seismometer: SP400 medium period
10	Minna	09°30.702'N	06°26.411'E	203	Granite	No instrument installed

Table 2. Information about response files parameters of the Entec sensors/Recorders at NNNSS (Courtesy CGG, Toro).

Stations	Free period (s)	Damping rate	Generator constant (V/m/s)	Digitizer sensitivity	Sampling rate	Amplifier gain
Kaduna	16	0.7	2000	419,430C/V	40	0.0
Nsukka	30	0.7	2000	”	”	”
Toro	60	0.7	2000	”	”	”
Awka	16	0.7	2000	”	”	”
Ife	60	0.7	2000	”	”	”

information regarding the equipment at the respective stations is shown in Table 2. The Awka, Kaduna, Nsukka, Ife and Toro are currently operational while installation of equipment at Abakilike, Oyo, Minna, Abuja, Ibadan stations would be completed soon. The sensors at Nsukka, Awka and Ife are placed in a vault of about 6-10 m deep in University communities with surrounding residential buildings, while the sensors at Kaduna and Toro stations are placed on the surface of a basement in relatively quiet environments and are about 100 – 600 m from light vehicular movement, and some surrounding trees. The NNNSS has been collecting data since 2008. While some stations are located few kilometers away from the Atlantic Ocean and some fast running streams in the Southern part of the country with surrounding human settlements, others are located farther away in the north with sparsely populated hamlets, no streams apart from surrounding trees.

Although, geologic foundation for each site was established before sitting of the five operational stations (Figure 1), no noise analysis was conducted at the site to ascertain the noise level and possibly identifying the sources of the noise. The study is intended to quantify the amount of noise present in the existing NNNSS data

Figure 2. A Eentec EP 105 sensor installed and insulated at Toro Station.

Figure 3. A DR 4000 Eentec recorder at Toro Station.

and compare with Peterson (1993) noise curves, since this simple comparison had been adopted to investigate the performance of seismic stations around the world. The spectra figures obtained from this study can be compared with those of Peterson's and see if they are behaving in line with the global standard (Figures 2 to 5 and Tables 1 and 2).

METHODOLOGY

The data in miniSEED format obtained from the five stations were used for this study. Average of an hour-long Z-component data for six month from each station and their respective noise spectra were plotted using spectral analysis method (Alguacil and Havskcov, 2010). With digital data like NNNSS's data, it is possible to make spectral analysis, and thereby get the noise level at all frequencies

Figure 4. A typical set up of NNNSS stations; this one at Toro station showing recorder, batteries connected to solar panels installed outside, computer monitor to temporary store data before they are downloaded and processed.

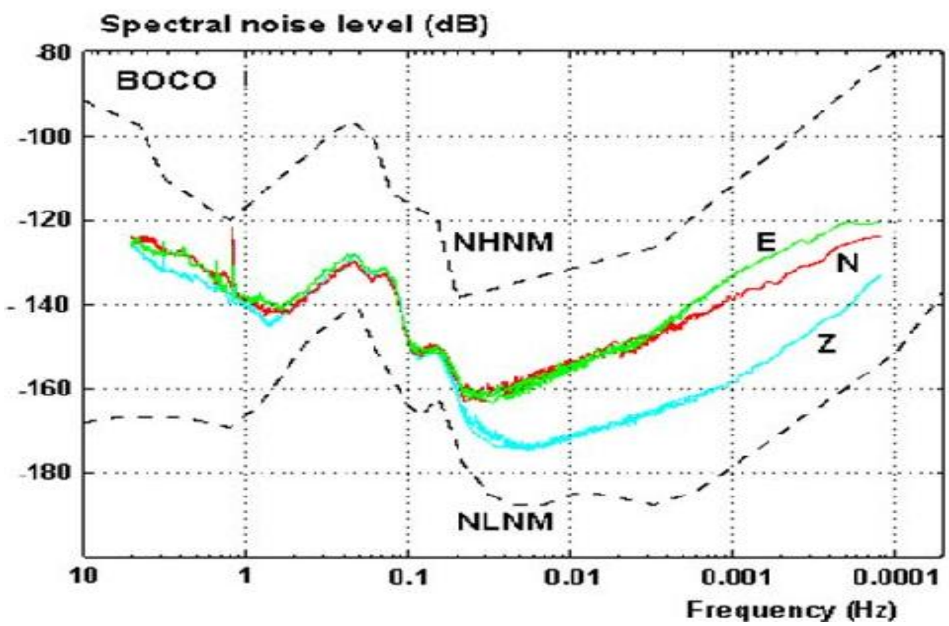

Figure 5. New global high (NHNM) and low noise models (NLNM) of Peterson (1993) and noise curves and noise spectral level for the IRIS station BOCO, which was considered a good station from this figure. The Peterson high and low noise models are shown with dashed lines (Havskov and Ottemoller, 2008; Alguacil and Havscov, 2010). However, other techniques like noise analysis using Pascal Quick Look Extended package and others can also be used to test for performance of seismic stations that give the Power Spectral Densities.

in one simple operation ((Alguacil and Havskcov, 2010; Chapman et al., 2006). The noise spectra is represented as the noise power density acceleration spectrum *Pa(ω)*, noise level is thus, calculated as:

$$\text{Noise Level} = 10 \log [Pa(\omega)/(m/s^2)^2/Hz] \quad (1)$$

It is also possible to relate the power spectra to amplitude measurements (Bormann, 2009). Approximate relationship can be calculated between the noise power density *N(dB)* given in dB and the ground displacement *d* in meters:

d = f-1.5/39 * 10N(dB)/20 (3.17) (2)

N(dB) = 20log(d) + 30log(f)+32 (3)

Where *f* is the average frequency of the filter and dB is relative to 1 $(ms^{-2})^2$/Hz (Alguacil and Havscov, 2010). Using Equation 2 or 3, noise level in dB and at various frequencies range can be computed.

Although, it can be used to realize other results, the spectral analysis is commonly used to make the correction of attenuation and instrument displacement spectrum and determine the flat spectral level and corner frequency from which the seismic moment, source radius and stress drop can be calculated (Ottemoller et al., 2012).

To determine moment, source radius and stress drop using spectral analysis, spectral option (Spec) is used with (d) for displacement, (v) for velocity, and (a) for acceleration or (r) for raw spectrum. However, instead of selecting d, v, a or r in Spec program (SEISAN), just press the same characters in upper case to make power spectrum and noise spectrum which is the interest of this study (Ottemoller et al., 2012).

Specifically, this study considered the seismic background noise which is often displayed as acceleration power spectral density in dB relative to ((1m/s**2)**2)/Hz. Instead of selecting d, v or a as mentioned, pressing n instead will show the Peterson (1993) new global high and low noise models superimposed on the observed spectrum as showed in the figures. As it is applicable when determining moment, source radius, and stress drop of an event from analysis, no attenuation correction is done when doing noise spectra (Ottemoller et al., 2012). Although, an hour-long window was used for the spectral analysis, the resulting spectrum according to Ottemoller et al. (2012) can be normalized using the following relation:

$$P = |F^{DFT}|^2 * \frac{\Delta t^2}{T} * 2 \qquad (4)$$

where P is the Peterson power spectrum, F^{DFT} is the discrete Fourier transform, Δt is the sample interval and T is the length of the time window. The factor 2 comes from the fact that only the positive frequencies are used so only half the energy is accounted for. The total power is proportional to the length of the time window since the noise is considered stationary, so by normalizing by T, the length of the time window should not influence the results. This noise option is a good and straightforward method of checking the noise characteristics of a given seismic station and compare it to global standards. This is exactly what we have demonstrated in this study, with limitations like plotting noise spectra in longer window and obtaining power spectra densities directly, which could be improved upon on in future.

RESULTS

There are several software that can give better results that we obtained here, but within the limit of spectral analysis technique in SEISAN software that was handy for this work, the noise spectra were plotted here. One hour long data collected on April 1, 2012 from Kaduna; July 1, 2012 from Nsukka; June 28, 2012 and June 30, 2012 from Awka; July 1, 2012; and June 3, 2012 from Toro and Ife stations respectively as compared to data collected for the six months were used, since there was no much deviation from month to month. It is pertinent to point out that observation of pattern or consistency of noise on the Z-component of the five stations (Figure 1) was conducted between January and July 2012 and average day time/night time noise as observed are represented in Figures 14 to 23. It is also assumed that the seasonal variation of noise is addressed in the analysis since the data convered six months. However, more detailed study that will clearly reflect seasonal variations in noise would be undertaken in future. The SEISAN software can plot power spectra but has limitation in the length of window for data spectral figures as one hour-long data were accommodated and averaged to get general overview of noise pattern. The amplitude and phase responses for the five stations are showed in Figures 6 to 10. It is a prerequisite to create the response files within CAL directory of SEISAN before performing noise spectral analysis. The response files give information about the instruments and the need or not for correction for instrument response. Figures 14 to 23 are the noise spectra for Z-component of the five stations and these spectra were compared with the Peterson (1993) curves and as showed in Figure 5).

DISCUSSION

Figures 6 to 10 are the amplitude and the phase response graphs from the Z-component of each station. These response files were created in the CAL directory of SEISAN software to test for the instrument information prior to the plotting of the noise spectra. Figure 11 shows noise traces from the five stations (from top bottom: Awka, Kaduna, Nsukka, Toro and Ife). PQLII was used toremove the mean and other trends from the traces before plotting the figures. It was clearly observed that Nsukka is more noisy followed by Awka while Toro is less noisy. Figure 12 shows noise spectra plotted with PQLII on the same window, having Nsukka with more amplified cultural noise and least on Toro. In this case, the noise spectra were not compared with Peterson (1993). Overlay of the noise traces in Figure 13 resulted in Nsukka (Green) and Awka (Purple) overshadowing other three stations of Ife, Kaduan and Toro. Figures 11 to 13 were plotted to demonstrate dominance of background noise of some stations over the others.

Ocean generated microseisms are constant source of energy and ambient seismic noise is dominated by two peak of microseism at 7.0 and 14 s period (Friedrich et al., 1998). A peak, which is known as microseismic peak or double frequency peak, takes place around 7.0 s.

At Ife Station (Figures 14 and 15), the primary and secondary microseismic peaks are distinct at 0.05 and 0.3 Hz, respectively. The observed cultural noise was

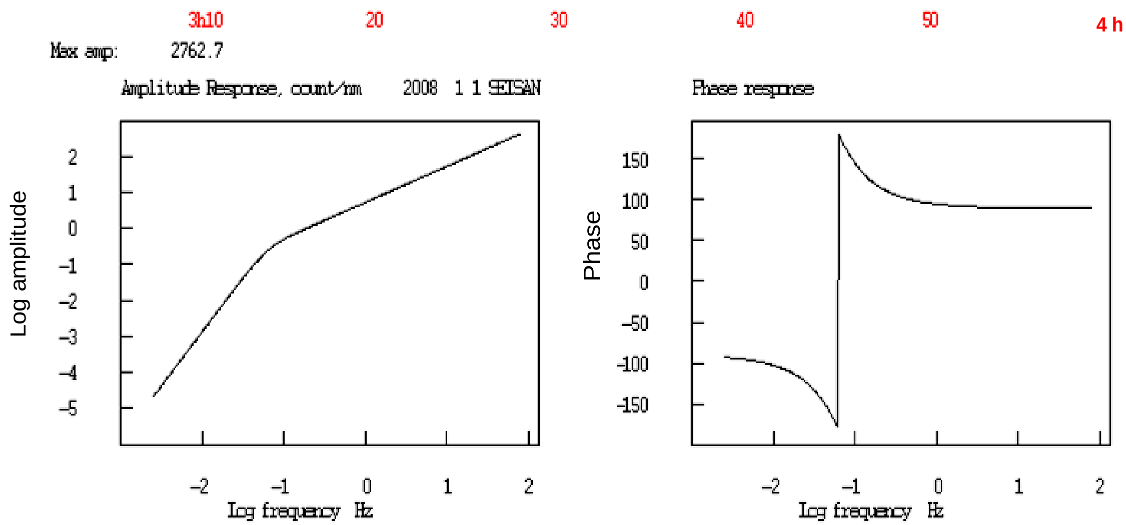

Figure 6. Amplitude and phase responses from Ife Station (Z-component).

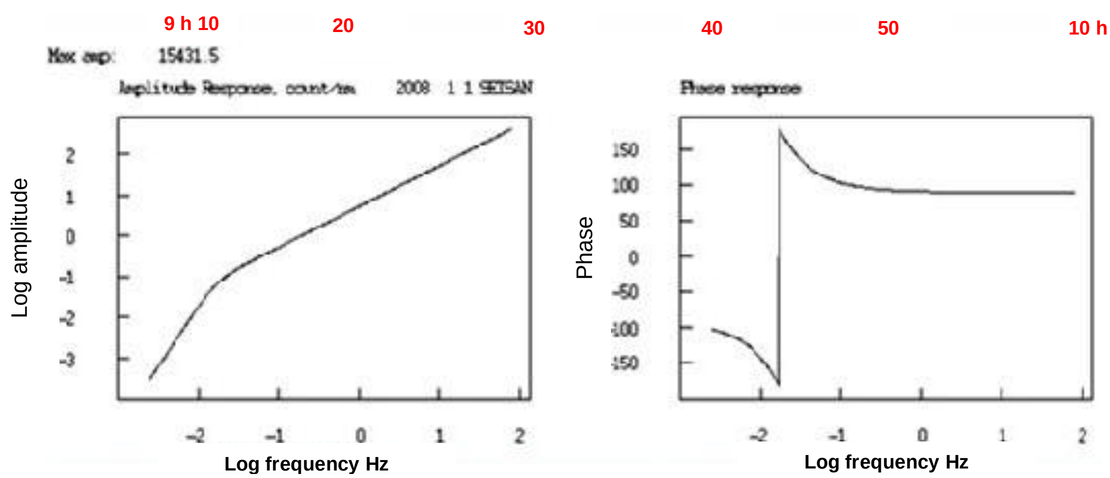

Figure 7. Amplitude and phase responses from Toro Station (Z-component).

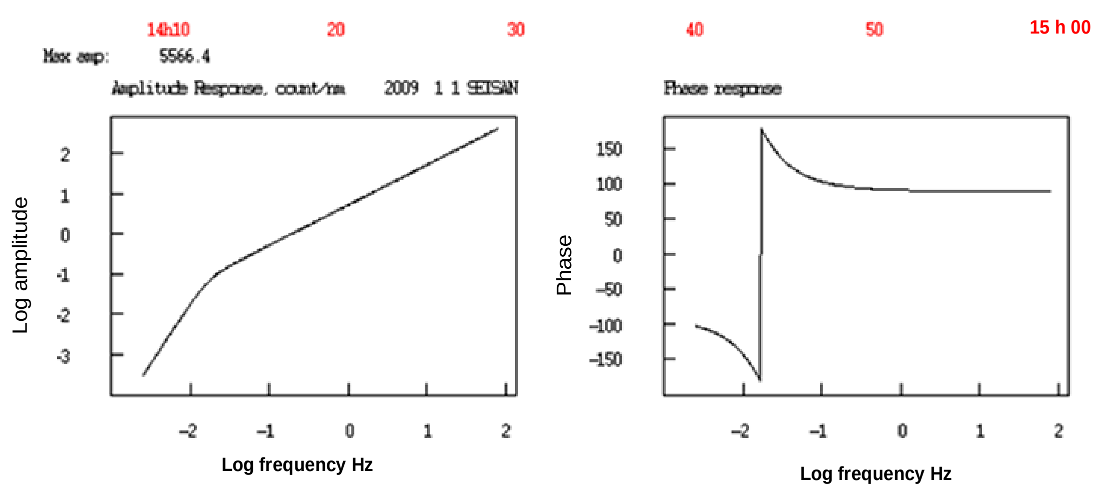

Figure 8. Amplitude and phase responses from Kaduna Station (Z-component).

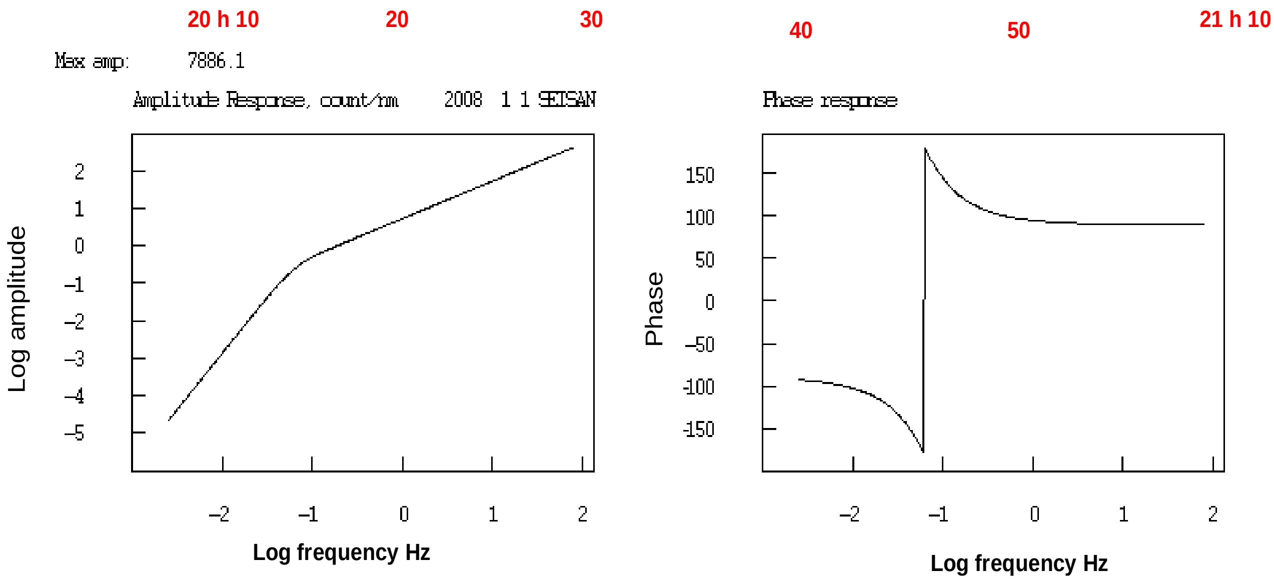

Figure 9. Amplitude and phase responses from Nsukka Station (Z-Component).

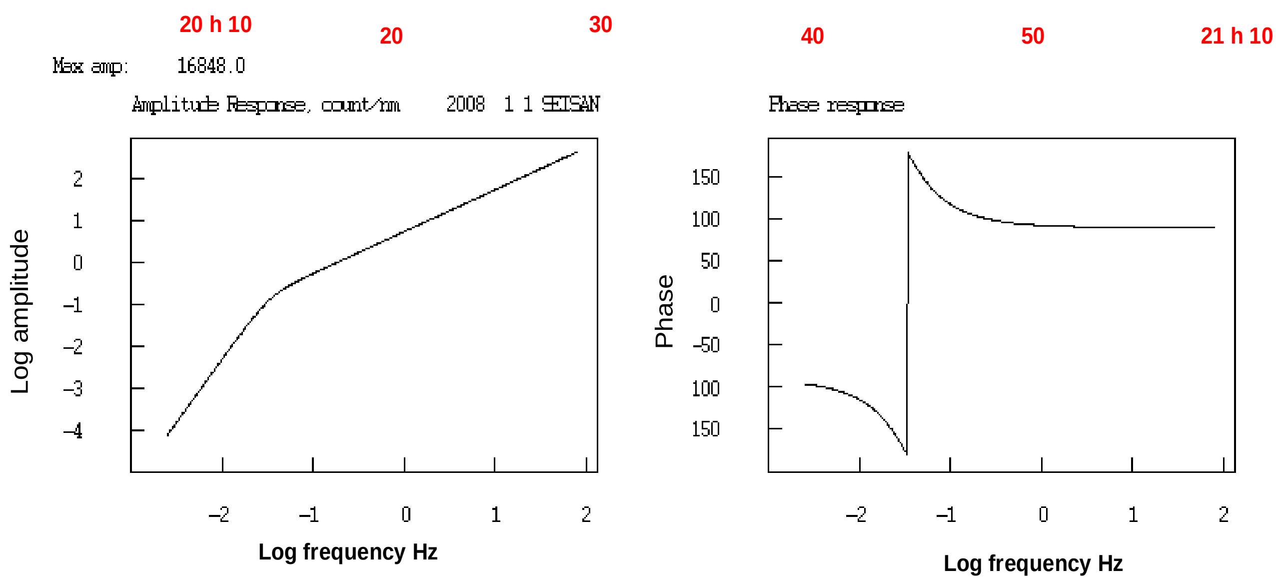

Figure 10. Amplitude and phase responses from Nsukka Station (Z-component).

slightly higher during the night time than in the day time, which is likely due to wind or rainfall or other sources of noise during the night the data was generated. The average noise spectra are good compared to the Peterson (1993) noise spectra curves. Between 0.1 to 2.0 Hz, both spectra assumed the shape of Peterson curve which represents the ground noise and station resolving power. Ife station is located in a quiet environment apart from surrounding trees, some running streams, and it is several kilometers away from the Atlantic Ocean in the southern part of Nigeria.

At the Nsukka Station (Figures 16 and17), the noise spectra are good compared to the shape of Peterson (1993) noise curves but cultural noise for both day time (10 am-12 noon) and night time (12 mid-night to 2 am) are very high likely due to wind and vehicular traffic, as the station is located far away from human settlements but about one kilometer from highway. Looking at Figure 16 and 17, it could be seen that there is no significant noise variation between day and night periods as high

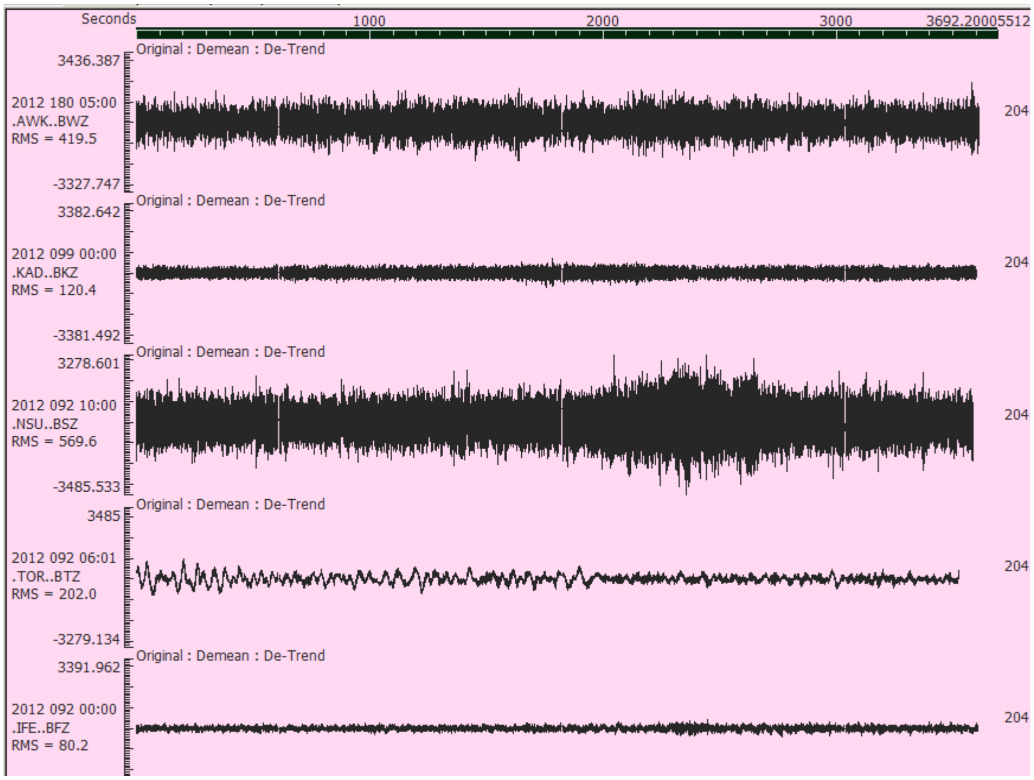

Figure 11. Showing noise traces (from top: Awka, Kaduna, Nsukka, Toro and Ife). No filters were applied, but the mean and other trends were removed.

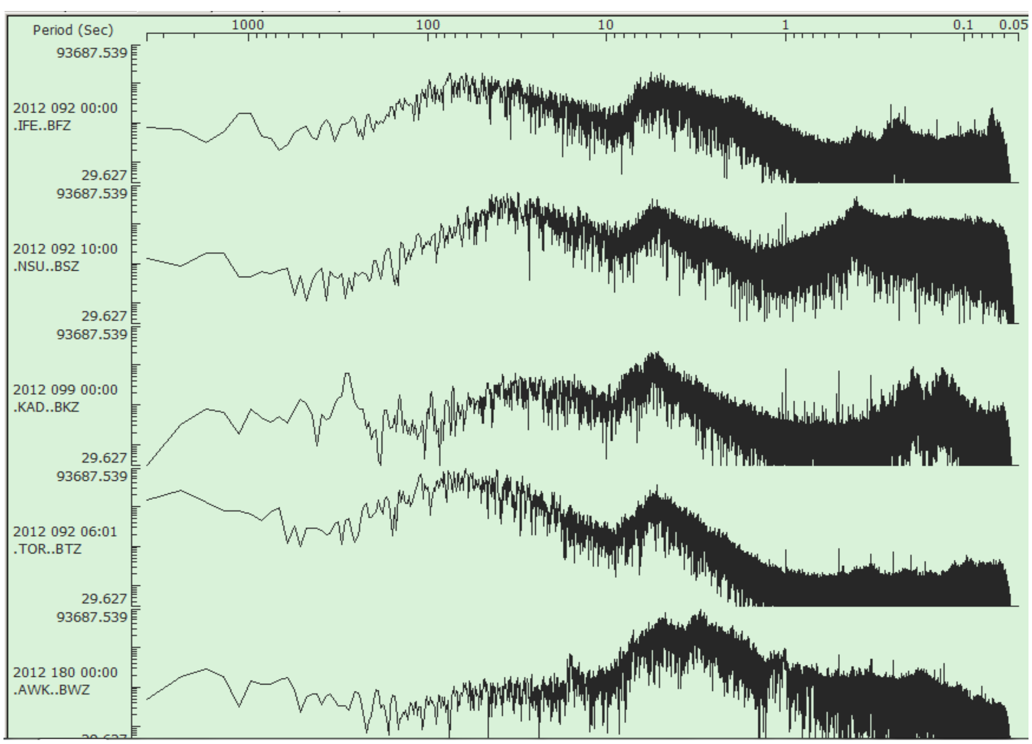

Figure 12. Noise spectra of (from top Ife, Nsukka, Kaduna, Toro and Awka). The spectra were here not compared with Peterson (1993) noise models.

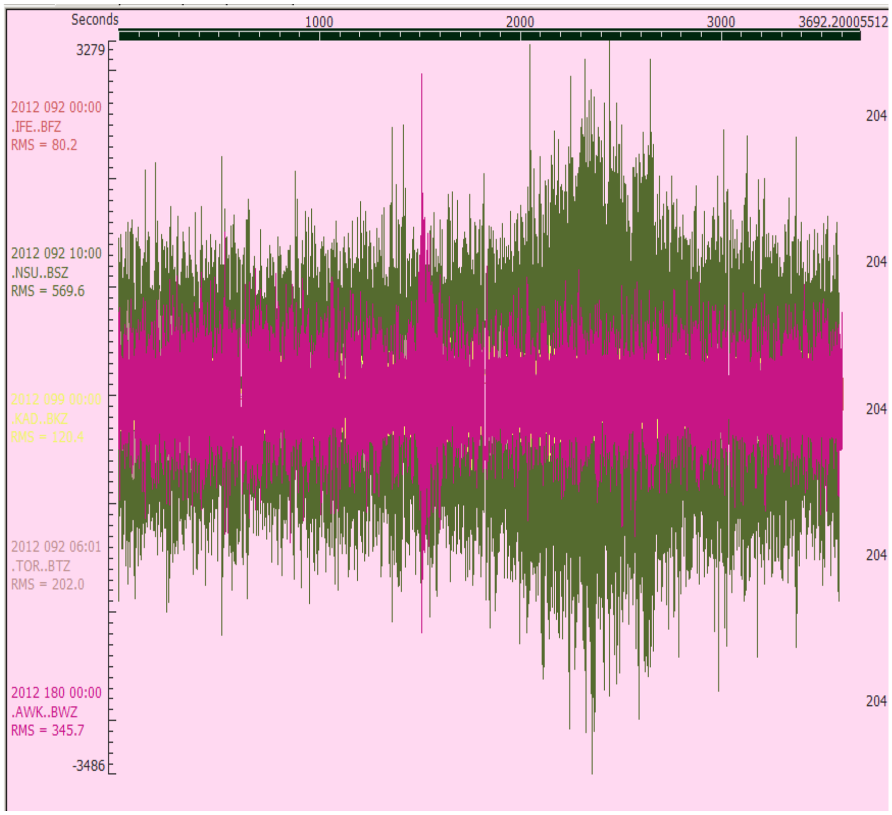

Figure 13. Overly of the Z-component noise traces (from the top to bottom: Ife, Nsukka, Kaduna, Toro and Awka).

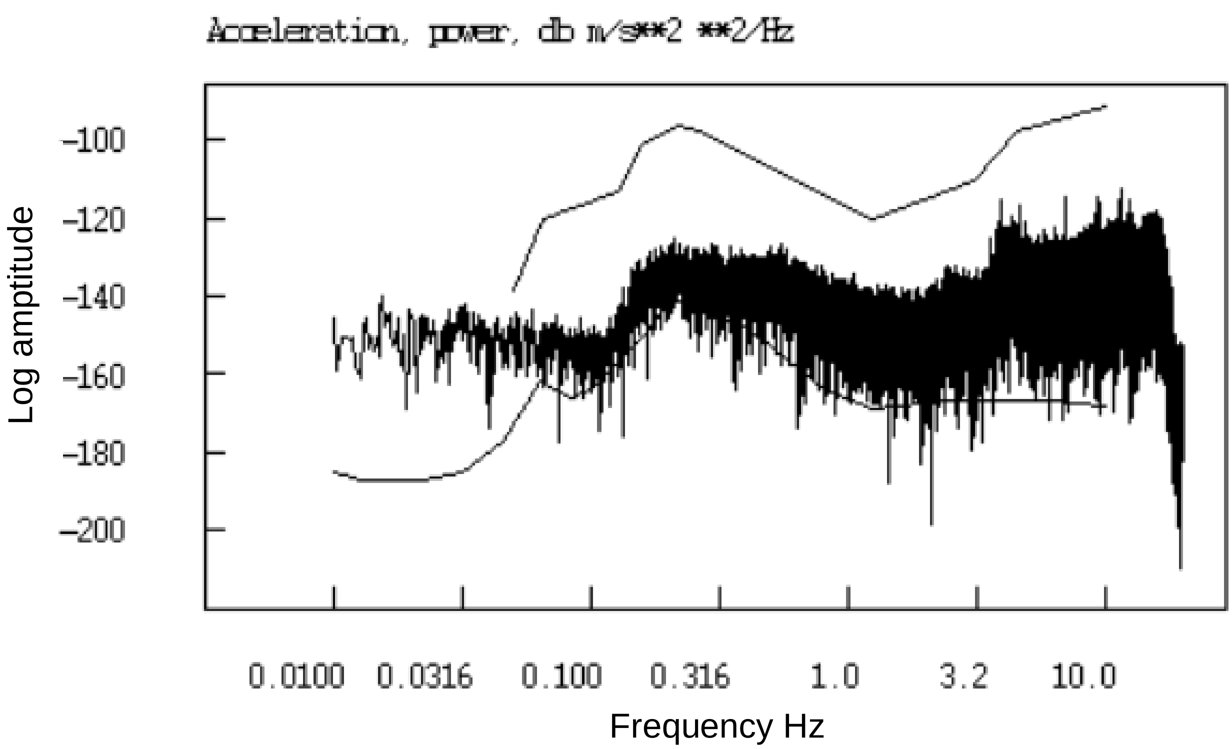

Figure 14. Noise variation between 12:00am – 4:00am (Ife Station).

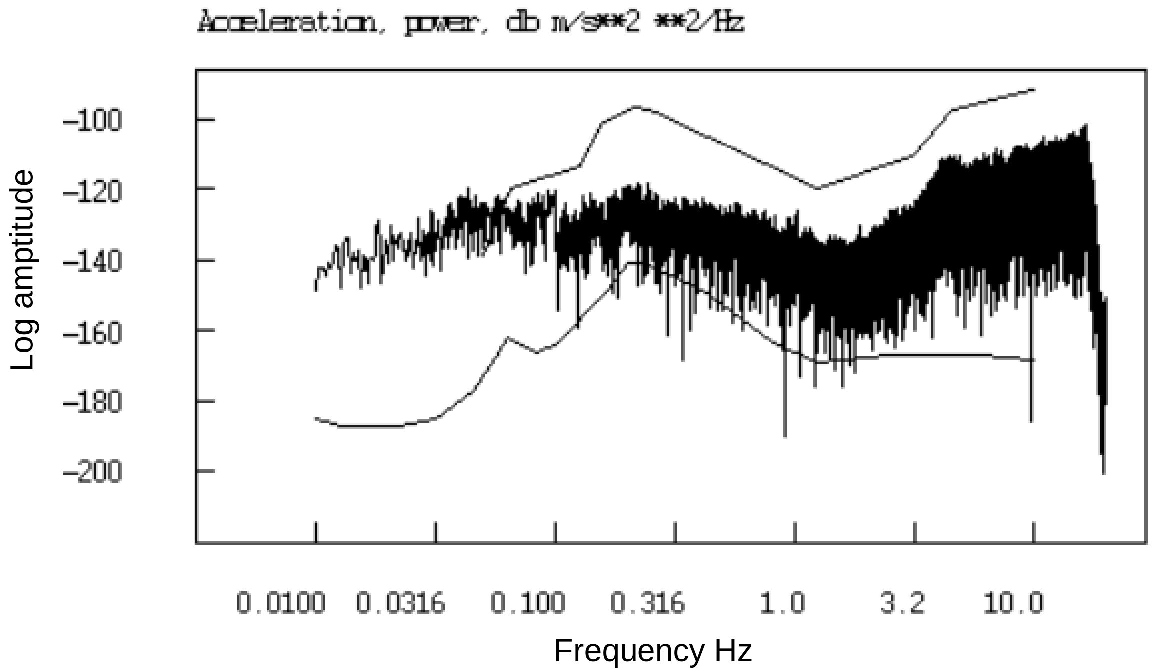

Figure 15. Noise variation between 11:00am-3:00pm (Ife Station).

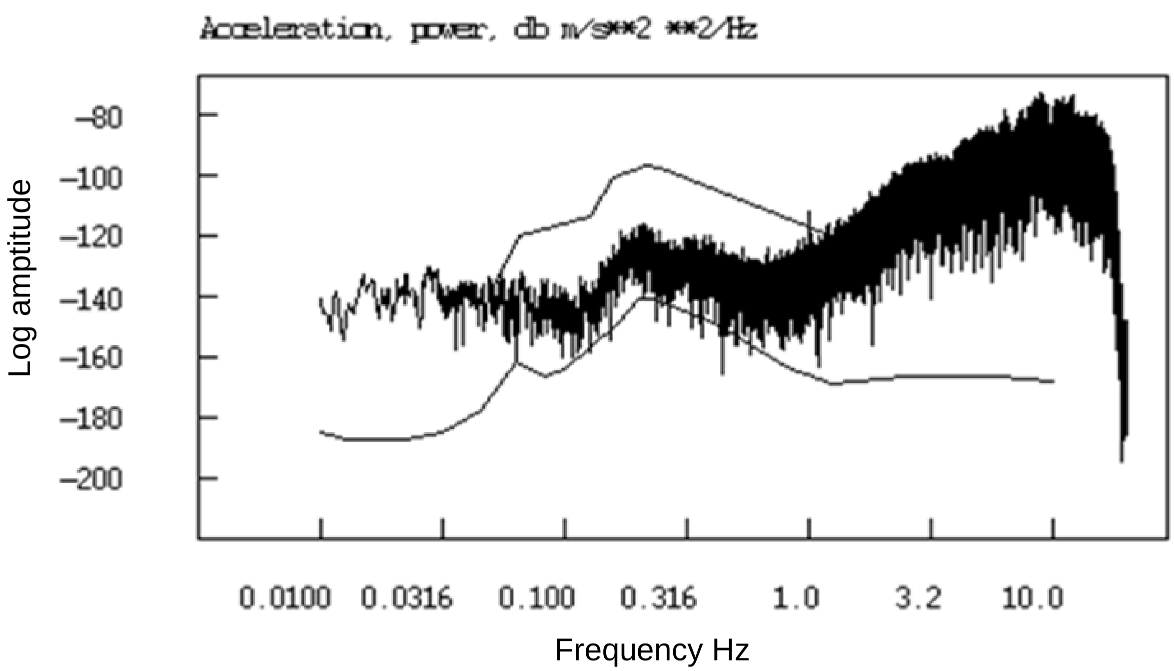

Figure 16. Noise variation between 10am -2pm (Nsukka Station).

level of noise was observed at the Z-component at high frequencies, that is, from 1 Hz and above and it is higher than the average Peterson noise curves (1993). At lower frequencies below 0.15 Hz, it was observed that the spectrum had almost the same shape as the Peterson curves which represents the ground noise and thus the resolving power of the station in that frequency range. The high noise level at high frequencies may indicate the

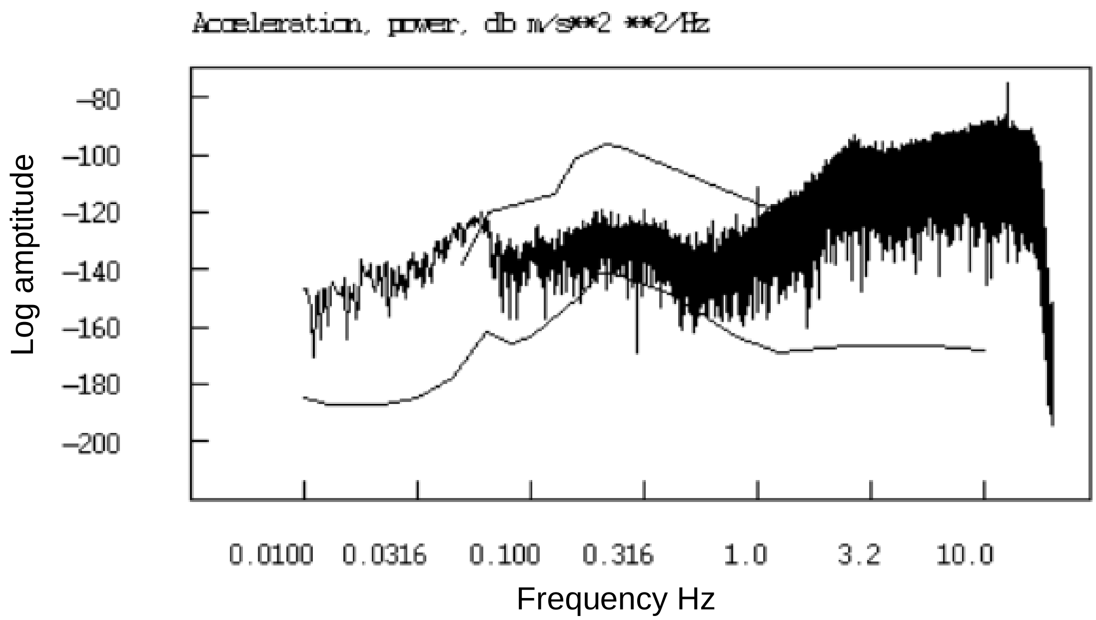

Figure 17. Noise variation from 12am-2am (Nsukka Station).

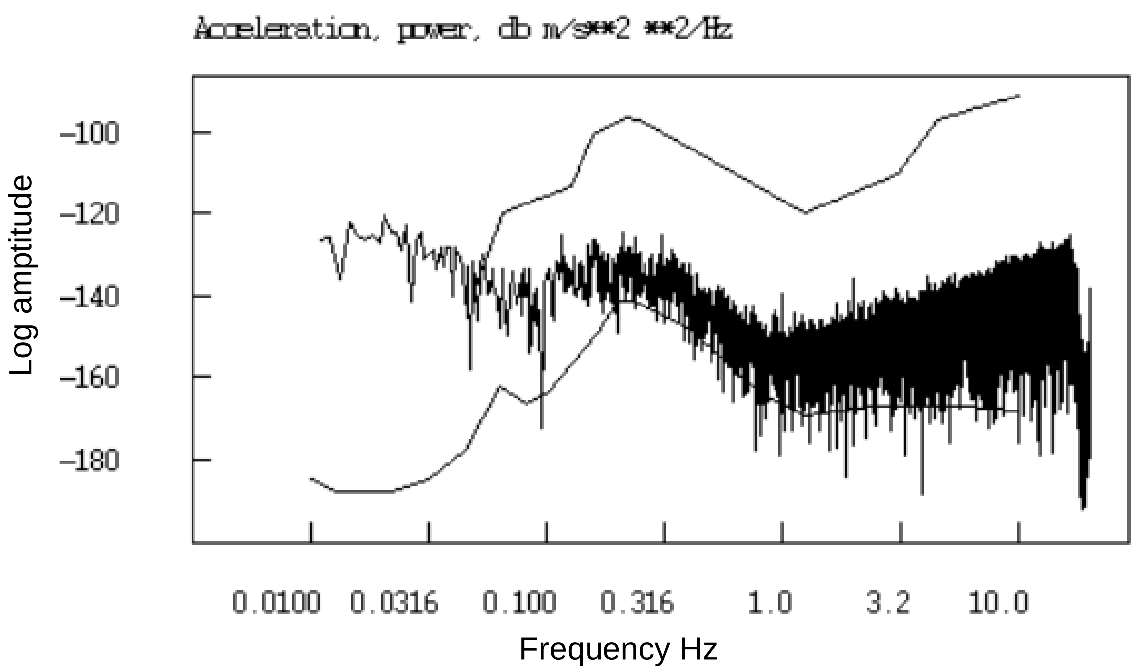

Figure 18. Noise Variation between 12am -3am (Toro Station).

contribution of cultural noise and on the lower periods (<1 s) maybe related to instrument self noise.

At Toro Station (Figures 18 and 19), although observed cultural noise at high frequencies is low on the average compared with Peterson (1993) noise curves, the noise is higher during the day time than during the night. Also, higher noise was observed at low frequencies between 0.01-0.1 Hz which is likely due to instrument self-noise. Since the sensor of this station is on solid, immobile rock hosting other monitoring equipment like Global Positioning System (GPS) etc., and with scanty settlements few meters away from the station, the likely sources of noise are wind, vehicular traffic, and human activities. Construction of a vault for the sensor would

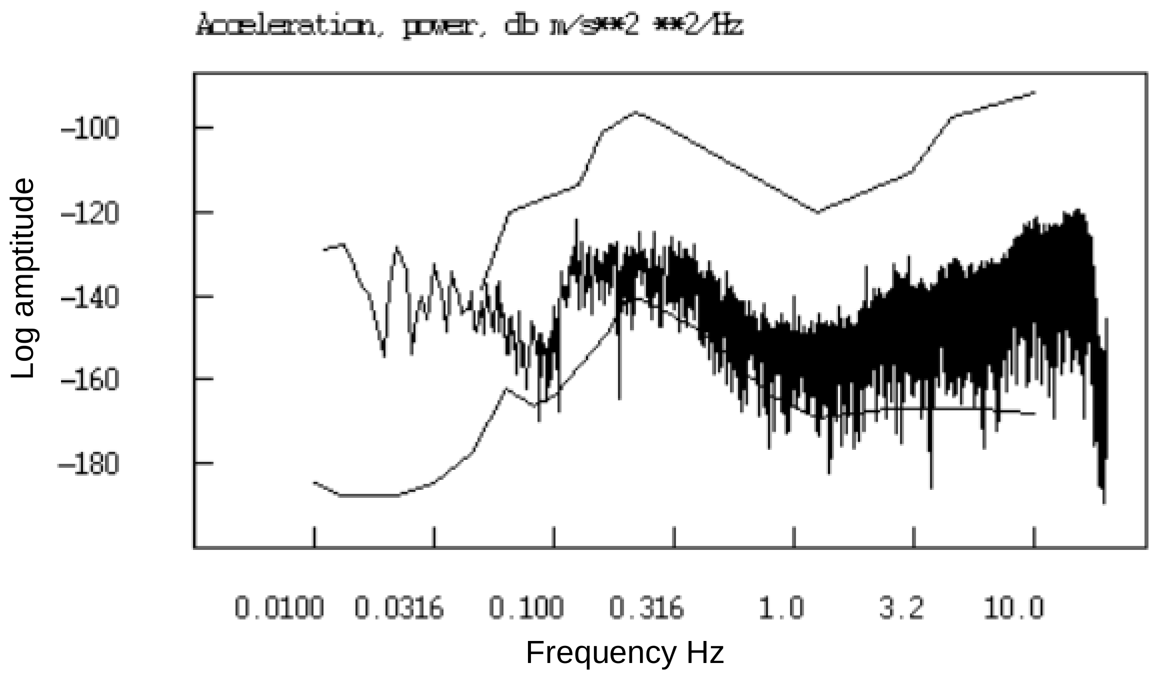

Figure 19. Noise Variation between 10am-2pm (Toro Station).

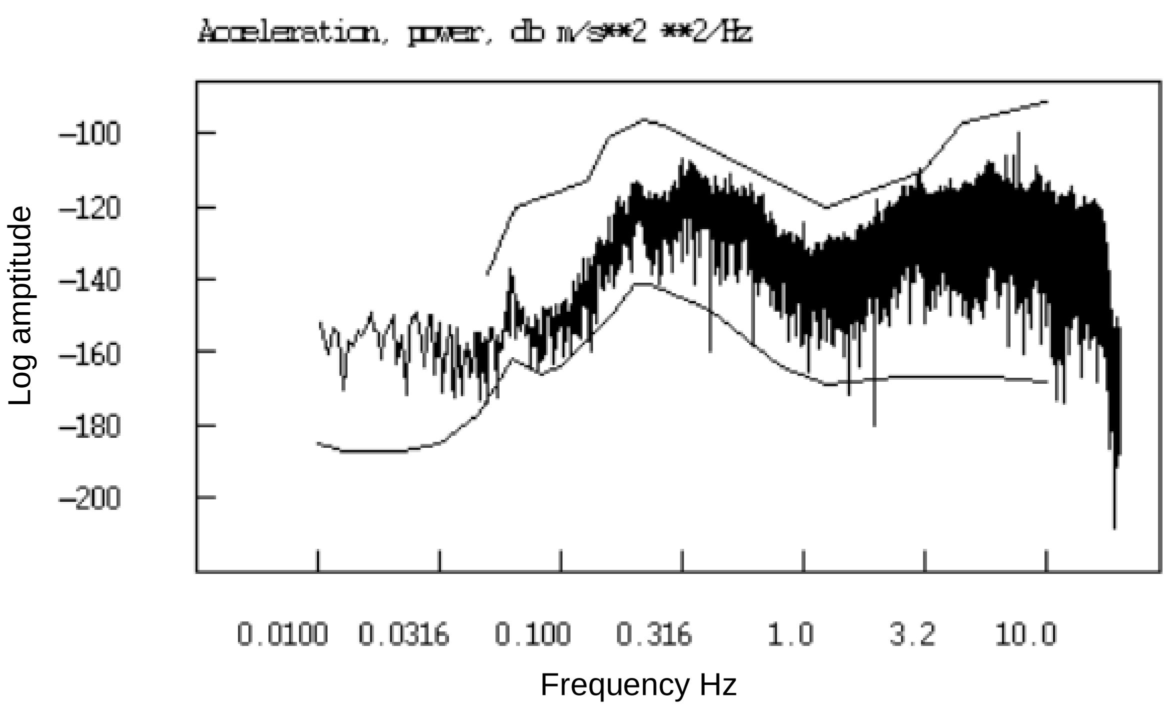

Figure 20. Noise variation between 9pm-12am (Awka Station).

likely minimize the observed noise.

At Awka Station (Figures 20 and 21), the noise spectra of the Z-component has the same shape as the Peterson curves at frequency band 0.1-10 Hz which apparently represents the ground noise of the station and of course the station's resolving power. The noise is low at lower frequencies between 0.01-0.1. The fairly high noise observed at higher frequencies above 1.0 Hz may be as

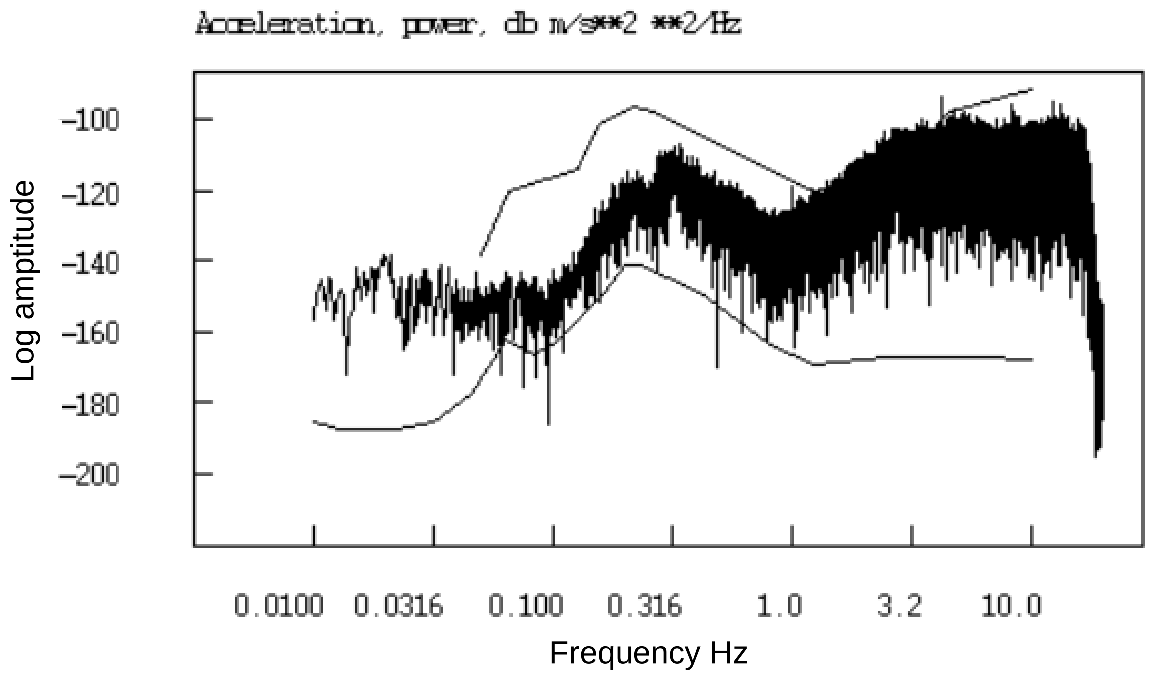

Figure 21. Noise Variation between 11am-2pm (Awka Station).

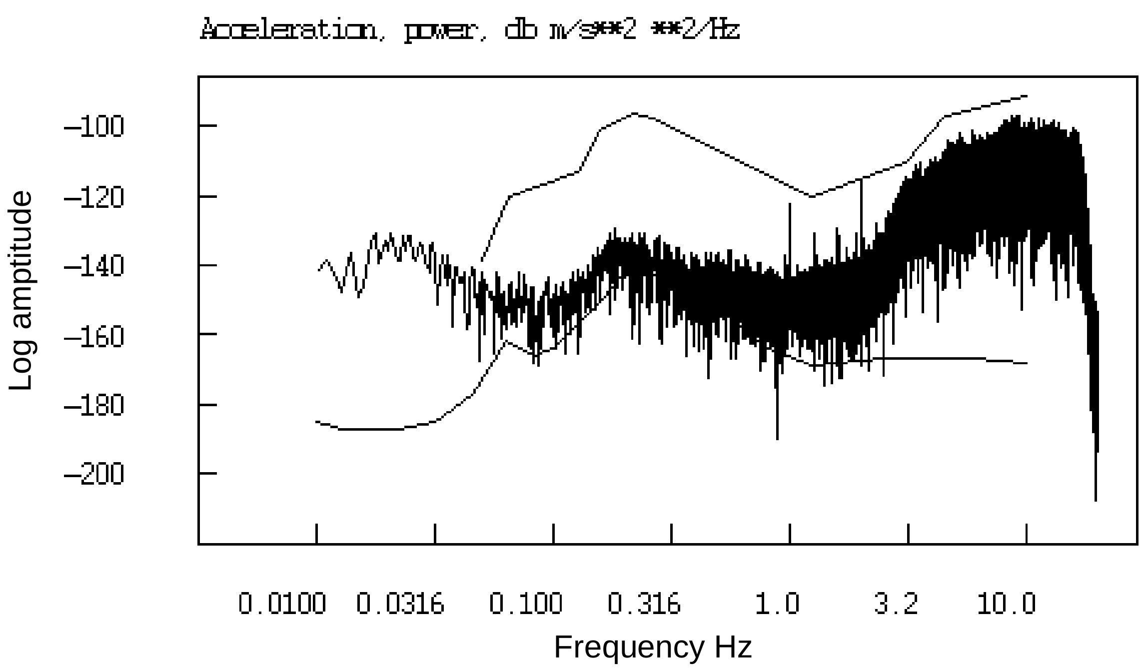

Figure 22. Noise variation between 9pm-1am (Kaduna Station).

a result of the contribution of cultural noise from the busy surroundings, it is a surprise that the noise is slightly higher during the night time than in the day time period. This may be due to windy condition or even rainfall, but the clear microseismic peak at 0.3 Hz is a clear indication that the station is a good station.

There is no significant noise variation at Kaduna Station (Figures 22 and 23) noise spectra are within acceptable frequency limits but noise is high at high frequencies between 3.2 and 6.0 Hz high noise level was

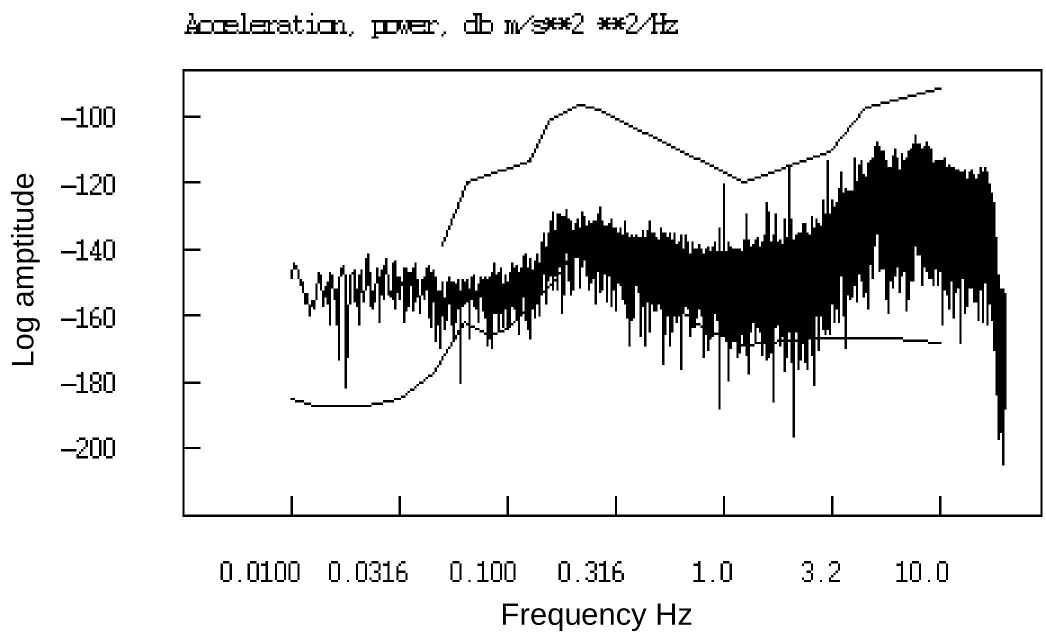

Figure 23. Noise variation between 9am-1pm (Kaduna Station).

also observed at lower frequency below 0.3 Hz. Since this station is located far away from busy settlements and heavy traffic, it is likely that the observed high noise at the Z-component is due to the contribution of cultural noise from human activities around the site, traffic and wind, noise from surrounding trees and instrumental noise.

Conclusion

Noise spectral analysis was conducted for all the NNNSS (Figure 1) and the various noise spectra (Figures 14-23) obtained were compared with Peterson noise curves and as observed in (Figure 5). The observed high levels of noise at the stations are likely due to a number of factors ranging from contribution of cultural noise to instrument self-noise. Since noise analysis was not carried out before the construction of these stations (Figure 1), it is highly encouraged to perform a more comprehensive noise analysis in order to understand the noise characteristics and the isolation of those stations must be provided in order to obtain better data quality and high S/N ratio. Also, the stations with observed higher noise level like Nsukka needed to be better installed and insulated. The orientation and leveling of the instruments should be checked and possibly instrument response and calibration files checked. Since this is a preliminary study, there is the need to undertake a site assessment to ascertain to a reasonable degree, SOURCES of seismic noise at each Station using recommended distances by Willmore (1979).

Abbreviations: NNNSS, Nigerian national network of seismographic stations; **CGG,** centre for geodesy and geodynamics; **SNR,** signal to noise ratio.

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