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A preliminary investigation of the signal-to-noise ratio of Toro and Nsukka stations in Nigeria

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Preliminary investigation of Toro and Nsukka stations from the Nigerian National Network of Seismographic Stations (NNNSS) with respect to Signal-to-Noise-Ratios (SNR) has been performed from noise observation and numerically. The results showed that Toro has higher SNR compared to Nsukka. Six months data collected from the stations in 2012 were used for the study. Nsukka Station in the southern part of Nigeria exhibited high noise than its Toro counterpart that is located in the North. This study is intended to investigate the causes of differing SNR at as observed at Toro and Nsukka stations respectively, with a view to adopting measures to forestalling SNR compromise at future stations in Nigeria.

Key words: Seismic noise, Nigerian national network of seismographic stations (NNNSS), signal-to-noise-ratio, measures for signal-to-noise-ratios (SNR) improvement**.**

INTRODUCTION

One of the primary reasons for siting seismographic stations anywhere in the world is to provide a platform for the monitoring of seismic activities (in the case of regions with low seismicity like Nigeria, United Kingdom, Canada etc); or for routine earthquakes' recording (for active regions like Japan, Indonesia, Turkey, East Afriacn Rift system etc) (Bormann, 1998). By the time one has successfully established seismic stations or network of seismic stations and generating data from them, the next consideration is the appraisal of the quality of data being generated from the stations (Trnkoczy et al., 2002a).

When a seismic trace is completely masked by seismic noise, the signal to noise ratio is in this case, seriously impaired. On the other hand, a station which has a high signal to noise ratio is considered a good station (Bormann et al., 2002). The paramount interest of a seismologist is to obtain data with less noise for research purposes. Therefore, one of the main issues in today's applied seismology is to ensure high signal-to-noise-ratios (SNR) by suitable ways of data acquisition and processing. However, the success of SNR improvement largely depends on our understanding of the ways in which seismic signals and noise differ (Bormann, 2002).

Recorded seismic signals always contain noise and it is important to be aware of both the source of the noise and how to measure it (Havskov and Ottemoller, 2008). Basically, noise observable on seismic trace is either noise generated by the installed seismic equipment or seismic noise from earth vibrations (ambient seismic noise). Sources of ambient noise include tides, water waves striking the coast, turbulent wind, effects of wind on trees and buildings, traffic or human based noise (Boonefoy-Claudet, 2006). Normally, the instrument noise is well below the seismic noise that it is often ignored in most cases (Alguacil and Havskov, 2002). Other sources of seismic noise include running water, surf and volcanic

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tremor (an almost harmonic noise associated to fluids motion, often lasting hours or days) or background activity as local sources of seismic noise (Alguacil and Havskov, 2002).

Ambient seismic noise can either be cultural or natural. The ambient seismic noise represents the microtremors and microseisms respectively. Cultural noise shows strong diurnal variations and it has characteristic frequencies depending on the distribution of the noise source (McNamara and Buland, 2004).

Installation procedures of seismometers contribute significantly to presence of noise from instrumentation. If seismometers are not properly installed it could lead to generation of self-noise or noise from external influences that cause high noise especially on the horizontal component of the seismometer (Wielandt and Forbriger, 1999). So in the process of selecting a site for permanent seismic stations, the issues of the type of infrastructure to be installed and how to achieve low seismic noise at the site are seriously considered. The noise level depends on the geological situation and on the proximity of sources, some of which are usually associated with the infrastructure. It is expected that a seismograph installed on solid basement rock will fairly insensitive to local disturbances while one sitting on a thick layer of soft sediments will be noisy even in the absence of identifiable sources (Wielandt, 2002). Since the inherent noise is the major determinant of the nature of SNR, avoidance of practices that introduce noise into recorded signal trace must be avoided. This work is aimed at comparing the SNR at both Toro and Nsukka stations from noise observation and computation, infer possible factors that improve or impair data quality and make useful suggestions on how to select a better site where SNR will be enhanced.

NIGERIAN national network ofseismographic stations

The location of the Toro and Nsukka stations are shown in (Figure 1). The installed equipment and geologic foundation at each site are shown in Table 1. The sensor at Nsukka is placed inside a vault of about 6 m deep in a University community with surrounding residential buildings, while that at Toro station is on the surface of a basement in a quiet environment apart from vehicular movements (approximately 30 to 200 m distant) and surrounding few houses and trees. Geographically, the stations at the southern part of Nigeria are located where there are dense vegetations, streams, rivers, and several kilometers away from the Atlantic Ocean, while stations sited in the north are on the basement, no streams, or close by rivers and very far away from the Atlantic Ocean. Toro and Nsukka stations are installed with Entec DR4000 Digitizer with 24-bit high resolution, 132 dB dynamic range, analog and digital alias filtering. The equipment are programmed to operate in both trigger and continuous mode simultaneously (Tables 1 and 2). According to the instrument's manual, the EETEC EP-105 seismometer is based on electrochemical transducer technology. The sensor has a dynamic range of 142 dB and bandwidth of 0.033 to 50 Hz

Abridged geology of Nigeria

Geology plays a significant role when siting a seismic station. So also observance of noise varies from site to site. Apart from being located within the intraplate area, Nigeria's land mass is made of Precambrian to Early Paleozoic crystalline basement rocks, about half of which is covered by sedimentary rocks of Cretaceous to recent age (Osazua, public presentation in Abuja, 2008). About two-thirds of the country's landmass is underlain by the Pre-cambrian basement complex consisting of gneisses, migmatites, schist, and various metamorphic rocks and granites (Figure 2).

These are in places intruded and interspersed by the "Older granites" which originated in the Pan-Africa Orogeny (Olujide and Udoh, 1989). Basement complex rocks outcrop in four main areas of the country: North of Rivers Niger and Benue, covering parts of Kaduna, Plateau, Bauchi, Kano and Sokoto States; southern Nigeria, covering the greater parts of Kwara, Oyo, Ogun; and Ondo States; southeast Nigeria, spanning the northern parts of Cross Rivers State and as far north as Yola; and north of Benue River in Gongola State (Eze et al., 2011). The Basement rocks are overlain by Cretaceous and Tertiary sediments of the seven major sedimentary basins, viz, the Calabar Flank, the Benue Trough, the Chad Basin, Iullemmenden (Sokoto) Basin, the Dahomey Basin, and the Niger Delta Basin. Sedimentary successions in these basins are of middle Mesozoic to recent age (Kogbe, 1989). In some cases, the Cretaceous sediments are cut by some major faults which may have been the result of the reactivation of post Pan-African fractures (Merki, 1970) (Table 3).

MEASURES FOR IMPROVING SNR

A high SNR translates to a good performing station. However, if the SNR is low, which of course will compromise the quality of the data, one of the various measures for SNR improvement abound. According to Bormann (1998) and Bormann (2002), these are: frequency filtering or band-pass filtering; velocity filtering and beam forming that frequency filtering cannot achieve; noise prediction-error filtering to determine the characteristics of a given noise field by means of cross- and auto-correlation of array sensor outputs; noise polarization filtering of 3-component recordings which allows one to reconstruct the ground particle motion and to determine its polarization (Shimshoni and Smith, 1964); SNR improvement by recordings in subsurface mines and boreholes and Signal variations due to local site conditions (Bormann, 2002). It has been demonstrated how short-period seismic noise is strongly reduced with the depth of sensor installation in boreholes or mines

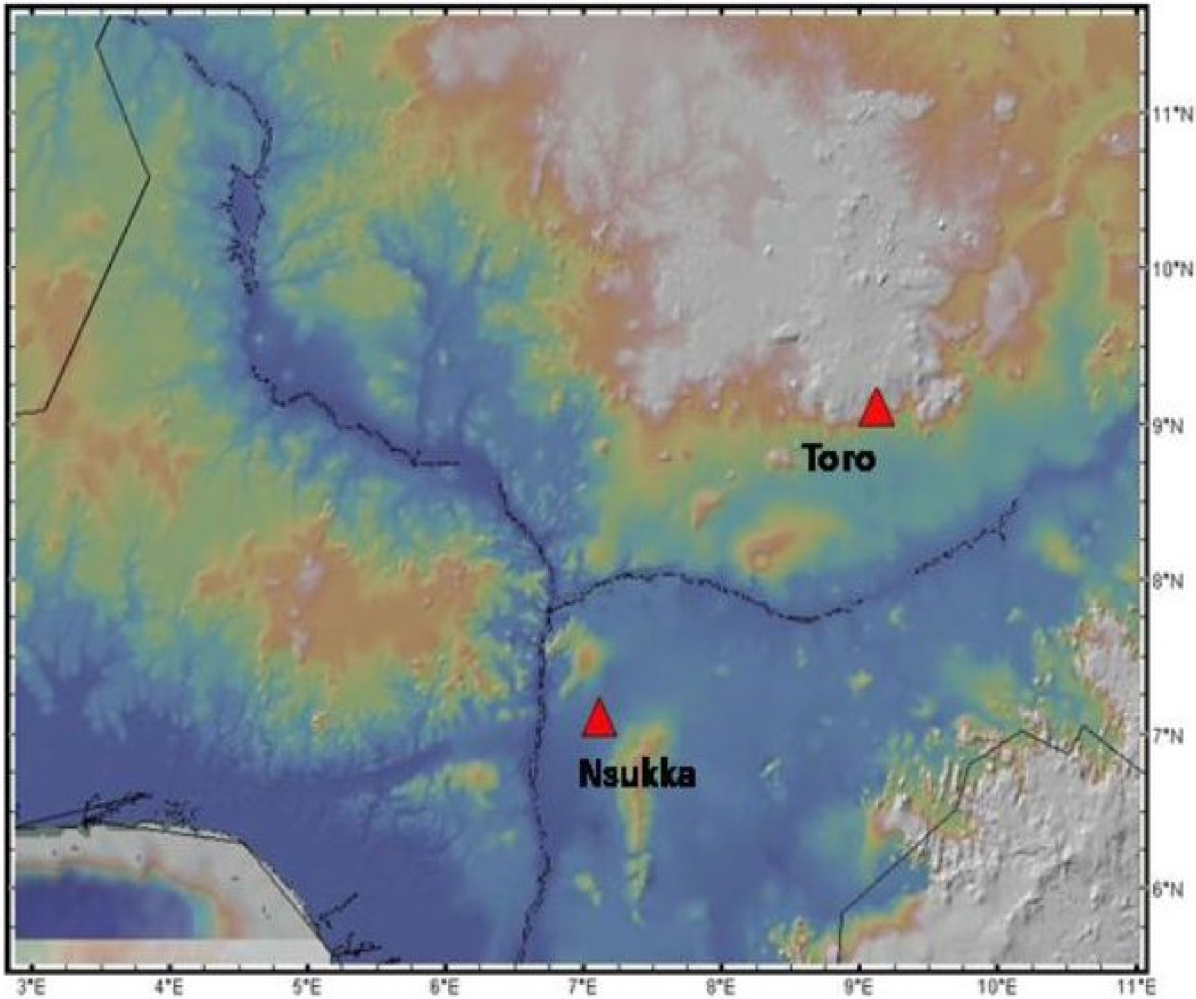

Figure 1. Map of Nigeria showing the locations of Toro and Nsukka stations (courtesy, GeoMapApp).

Table 1. Location of centre for geodesy and geodynamics seismological stations.

S/N	Station name	Latitude	Longitude	Elevation (m)	Geologic foundation	Instrumentation
1	Nsukka (NSU)	06°52.011'N	07°25.045'E	430	Sandstone	Seismograph: DR4000 recorder Seismometer: EP105 broadband seismometer
2	Toro (TOR)	10°03.303N	09°07.089'E	882	Gneiss	Seismograph: DR4000 recorder Seismometer: EP105 broadband seismometer

Table 2. Properties of Toro and Nsukka Stations.

Station	Free period (s)	Damping rate	Generator constant (V/m/s)	Digitizer sensitivity	Sampling rate	Amplifier gain
Nsukka	30	0.7	2000	“	“	“
Toro	60	0.7	2000	“	“	“

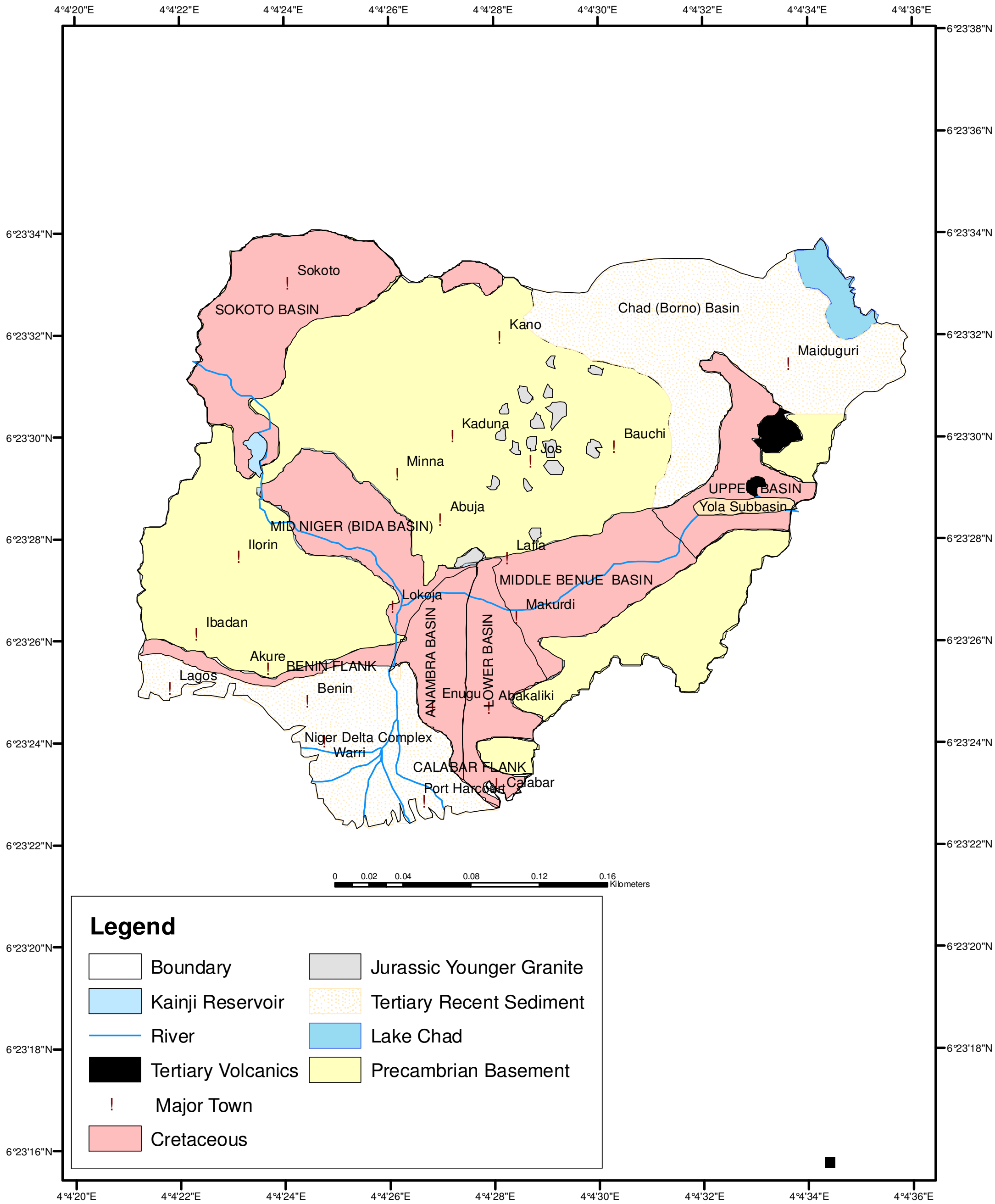

Figure 2. Map of Nigeria showing geology of the country.

Table 3. Classification of different types of outcropping geological formations in quality categories.

S/N	Different types of outcropping geological formations in quality categories
1	Unconsolidated (alluvial)sediments (clay, sands, mud)
2	Consolidated clastic sediment (sandstone, marls)
3	Less compact carbontic rocks, less compact metamorphic rocks, conglomarates, breccias
4	Compact metamorphic rock and carbonic rock
5	Magmatic rocks (granite, basalts)

Grade 5 is the best rock for seismic recordings and grade 1 is the worst according to Vidrih (2001).

Figure 3. Unfiltered trace from Nsukka Station, very difficult to identify the phases.

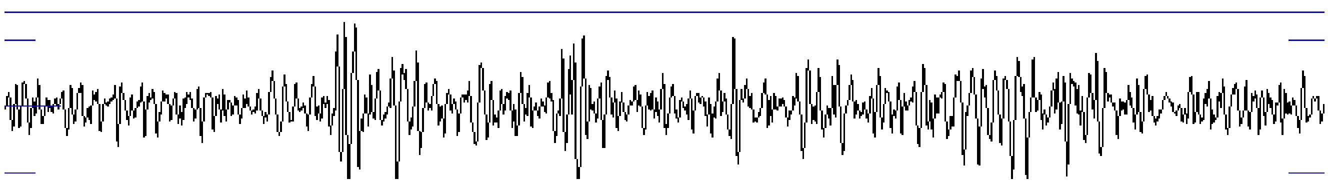

Figure 4. Filtered trace from Nsukka (using 0.01 to 0.1Hz filter band), the signal-to-noise ratio is much improved and later phases are clearly recognizable since the microseisms have been removed by filtering (courtesy: Havscov and Ottemoller, 2008).

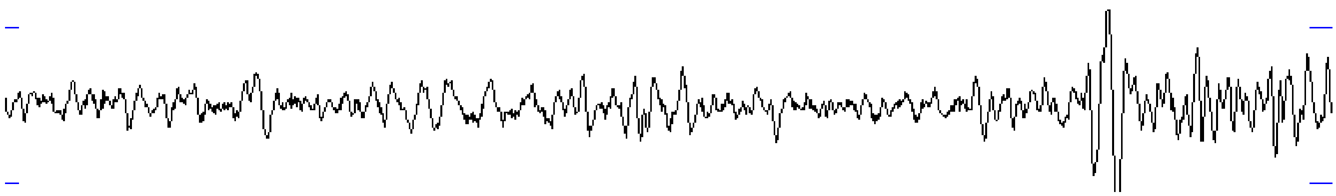

Figure 5. Unfiltered trace from Toro station from 2012-04-11-010-09M.NSN_003.

(NMSOP Chapter 4). However, when installing seismometers at depth, one must also consider effects on the signal, since SNR does not necessarily increase steadily with. This is due to the free-surface effect, peculiarities of the local noise field and geological conditions (Bormann, 2002). Also, while one station of a network may record events rather weakly from a certain source area, the station may do as well as other stations (or even better) for events from another region, azimuth or distance (Bormann, 2002) (Figures 3 to 6).

RESULTS AND DISCUSSION

There are various ways signal-to-noise ratio can be determined. Each method depends on the kind of signal of interest. Since the work is concerned with seismic signal, we can conveniently consider the following equation for SNR computation for both stations (Free encyclopedia):

$$\mathrm{SNR_{dB}} = 10\log_{10}\left(\frac{A_{\mathrm{signal}}}{A_{\mathrm{noise}}}\right)^2 = 20\log_{10}\left(\frac{A_{\mathrm{signal}}}{A_{\mathrm{noise}}}\right).$$

A_{signal} and A_{noise} are the maximum amplitude of the signal and noise of the trace respectively (Russ, 2001; Gonzalez and Woods, 2008). The (log) of the result was finally multiplied by a factor of 10 or 20, depending on the one you are using, to obtain the SRN in logarithmic decibel scale (dB).

If you are measuring sound waves, for example, it is important to know how background noise might interfere with your signal. Understanding the signal-to-noise ratio can give you a better idea about the signal you are interested in. In this study, the above equation was used to compute the maximum amplitude ratio using SEISAN open source seismological software (Havscov and Ottemoller, 1999). The signal to noise ratio of Toro station was found to be 38.7 compared to that of Nsukka station that is 9.8. Other methods can of course, be applied in the future to compare with these results.

Meanwhile, we may not completely right off Nsukka station as a bad station since from standard consideration, a good station has SNR>3. But since the SNR of Toro is almost four times greater than that of Nsukka, it is imperative to take measures that would help to improve the SNR of Nsukka station for better data quality. From Table 1, it is clear that Toro and Nsukka stations are respectively located on basement and sediment respectively, which could be one of the reasons for the sharp SNR differences. SNR is important for magnitude determination. If S:N > 3 the station is considered good otherwise there is a problem.

Figures 7 to 12 were constructed using noise estimation open source software, PQLII, with RAW data obtained from Toro and Nsukka stations at same period in 2012. For space and other considerations, all the figures

Figure 6. Filtered trace using 0.01 to 0.1Hz band-pass of the Toro station. Good SNR at this station does not give room for a distinct difference between Figures 4 and 5, unlike as observed in Figures 2 and 3.

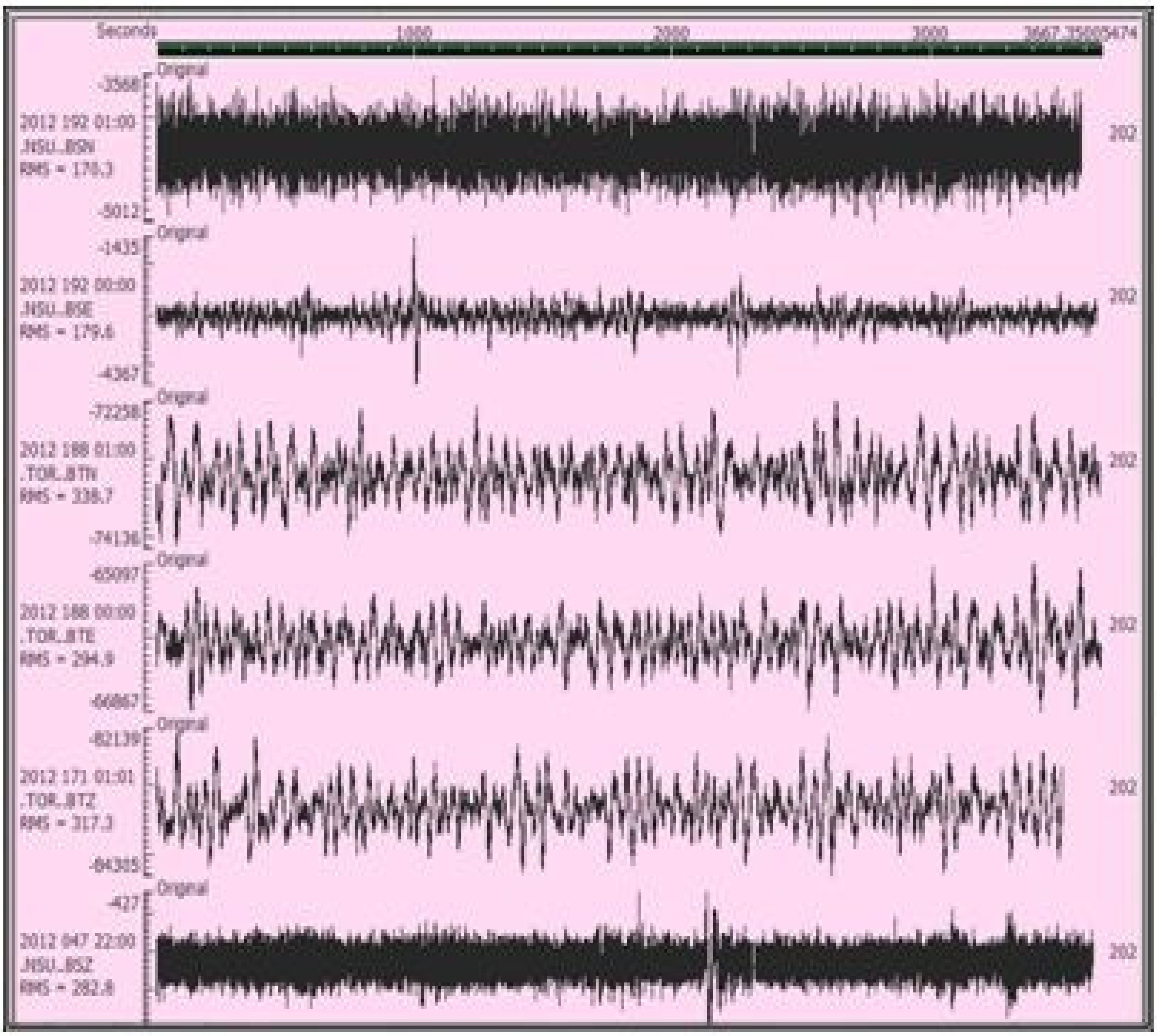

Figure 7. Traces of Z, N, E, components from Toro and Nsukka stations. High noise levels are clearly observed on the components of Nsukka station. If for instance there is an event at the time the seismic traces from Nsukka in this figure were recorded, the event will be completely shrouded by noise, thereby compromising quality of the signal. This is not good for signal to noise ratio of a station.

derived from the noise analysis for six-month period are not presented here. However, Figures 7 to 12 summarily compared the noise levels from both stations. Figures 9 to 12 clearly demonstrated the dominance of

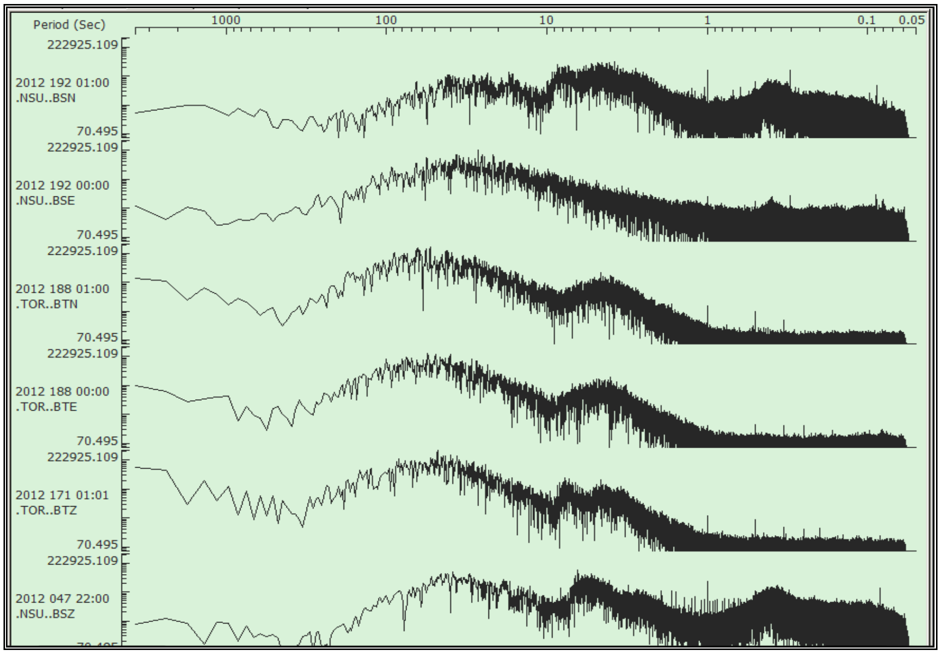

Figure 8. Spectral figures from the three components of Toro and Nsukka stations. The spectra from Nsukka station (first, second and sixth in the figure; especially the first and sixth spectra) exhibited high noise at high frequencies compared to the spectra of Toro station (third, fourth and fifth spectra in the figure). It is likely as a result of the contribution of anthropogenic noise from surrounding human activities and natural noise sources like wind.

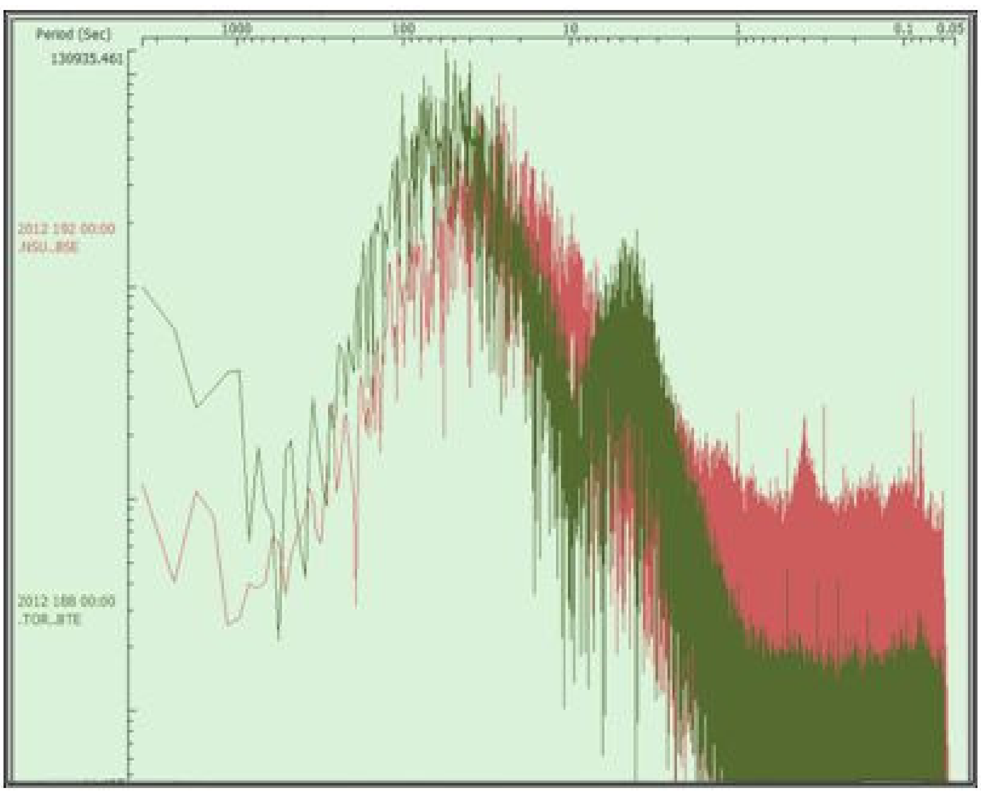

Figure 9. Overly of the Horizontal component of Toro and Nsukka showing higher noise on the Nsukka component (pink colour). The green colour represents trace from Toro.

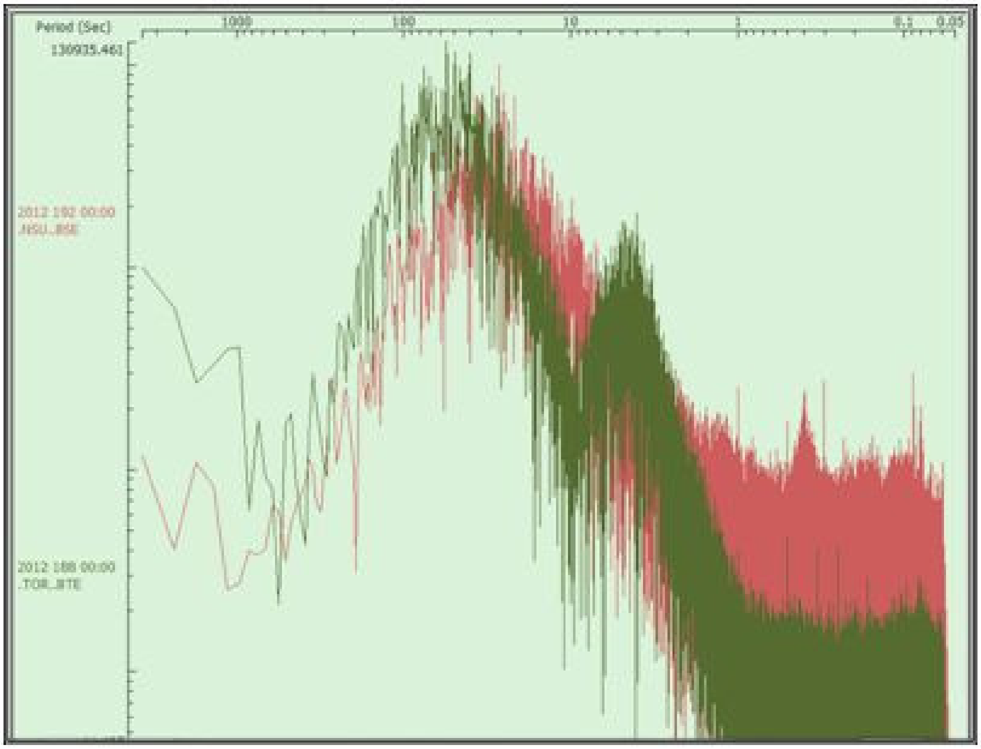

Figure 10. Overly of the vertical (Z) component of Toro and Nsukka showing higher noise on the Nsukka component (green colour). The red colour represents trace from Toro.

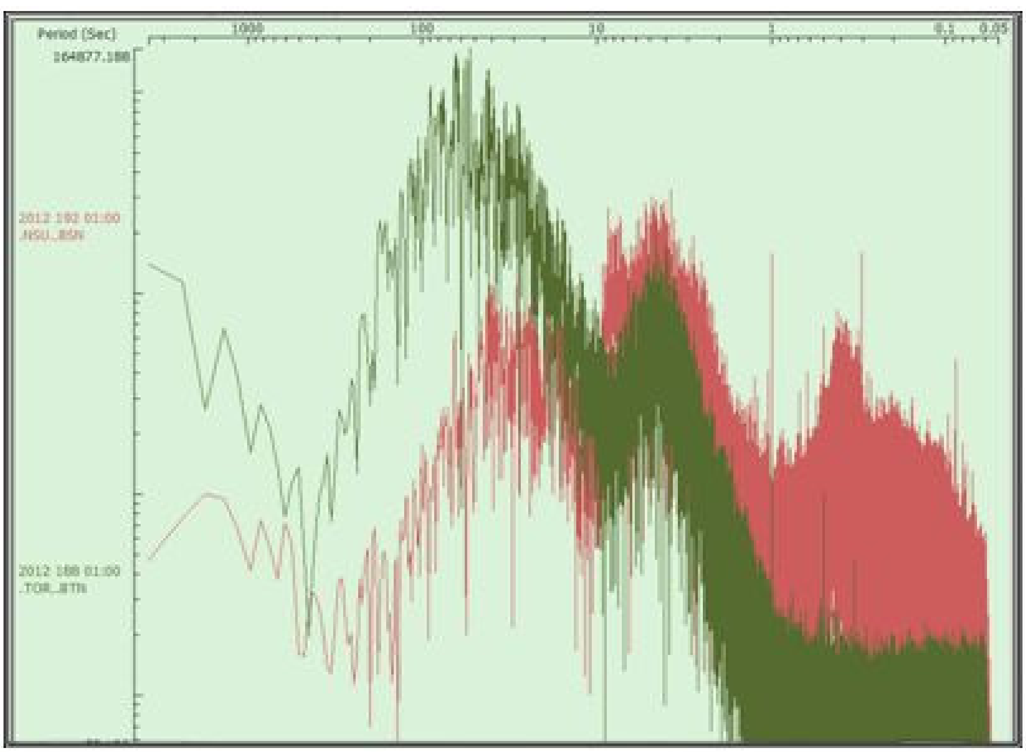

Figure 11. Overly of the N component of Toro and Nsukka showing higher noise on the Nsukka component (pink colour). The Green colour represents trace from Toro.

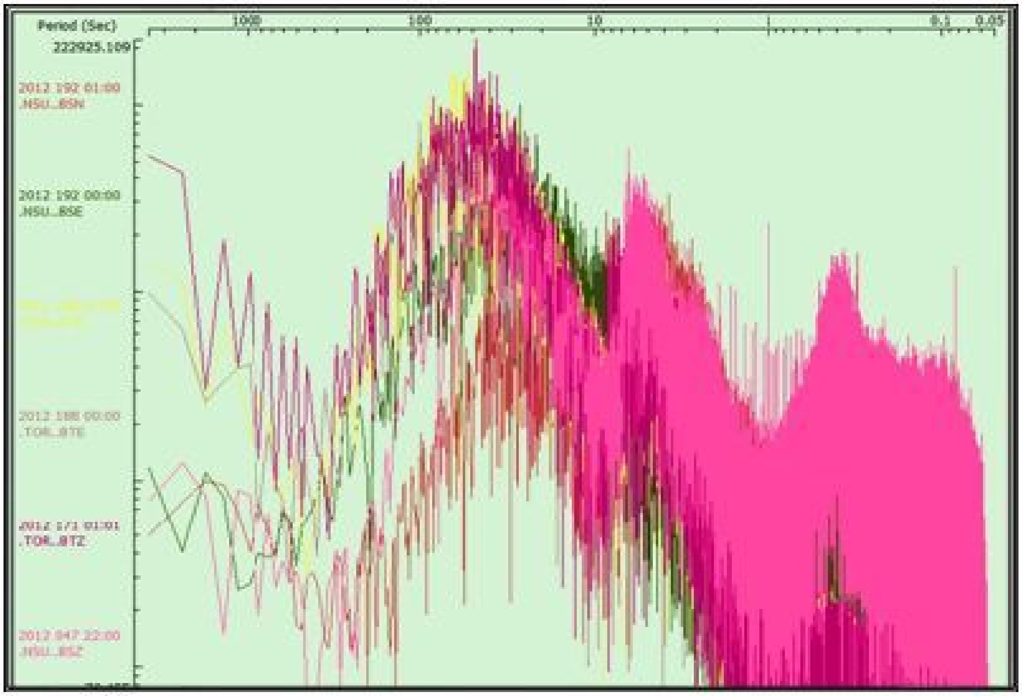

Figure 12. Overly of the three components of Toro with three components of Nsukka showing a remarkable higher noise on the Nsukka component (pink, green and red colours). The yellow, light pink and black colours traces represent Toro station, which are almost covered by the dominance noise from Nsukka.

noise on the Z, E and N components of Nsukka over Toro, using data from the stations and collected at the same time.

Conclusion

The performance of the two Nigerian Seismographic Stations: Toro from the northern part of Nigeria and Nsukka in the south had been compared. The pattern of noise as observed from the stations within a six month (January-July, 2012) revealed a consistent high noise on Nsukka data while data from Toro exhibited a relatively low noise. The low signal to noise ratio as observed at the Nsukka is likely due to the presence of sediments where it is sited, while that of Toro sited on hard rock has high SNR. Another reason that may be responsible for the noise at Nsukka cum low SNR, could be as a result of the low-period sensor (16 s) installed there. Improving data quality translates to improving site quality and this could be achieved at Nsukka if a better site is selected and/or increasing the depth of the vault to a reasonable depth to the bedrock and installing high-period sensor of say, 100 or 120 s (Trnkoczy et al., 2002b). However, the increase in the depth of the vault should not compromise the signal from the station as this would create another problem. This study was carried out within the limit of available tools and techniques. However, there are several ways or methods that could be adopted to check the performance of stations which include the use of Pascal Quick Look Extended (PQLX), Quack, etc.

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