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A Preliminary Evaluation of Broadband Stations in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author KUA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors TAY, HTS, OO, HK and MDC managed the analyses of the study. Authors KUA and HTS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Preliminary evaluation of the performance of the Broadband Seismic Stations in Nigeria has been carried out. The aim is to test the recording capability, data quality for research and estimate the signal to noise ratios of the stations. The methodology involves the noise analysis for the Kaduna station located on basement complex in the northern part of Nigeria, and Nsukka station on the sedimentary basin in the South, using the Pascal Quick Look Extended (PQLX) package. In the first instance, data used in the research were continuously recorded during 2010 for 1-year period. Power spectral densities were computed from one-hour long data segments from both stations. Secondly, possible sources of noise to the stations as well as their signal to noise ratios (SNR) were estimated. Results from the first and second approaches were compared with the global noise models of Peterson's. Thirdly, data from both stations were tested for research reliability using noise correlation and receiver functions techniques. The results showed high noise levels at both stations; low SNR at Nsukka and high SNR at Kaduna. Findings also showed that sources of noise

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to the stations are both natural and anthropogenic in nature. Results from noise correlations and receiver functions indicated that the correlations are antisymmetric indicating that the noise sources are non-uniform. The seasonal variations of the noise were also observed on the monthly correlations. The receiver functions computed from Nsukka station did not provide a sufficient number of receiver functions. There was no clear Moho conversion at Kaduna station and the results of H-K stack were poor. Findings from this study are expected to serve as references towards illuminating operational impediment associated with broadband stations in Nigeria and useful measures have been provided in this paper to improve data quality for healthy research.

Keywords: Nigeria; broadband stations; signal to noise ratio; noise analysis; noise correlation; receiver function.

1. INTRODUCTION

Nigeria is not located in a seismically active region; however, couple of historical and instrument earthquakes have been observed in the country between 1933 to 2016. Information on earthquakes in Nigeria are well documented in [1,2,3]. Although impacts from these earthquakes were minimal with no loss of lives, and with impacts on structures in few cases which made the need to establish a network of seismographic stations in the country for efficient local earthquakes monitoring very imperative. The network is also to enable the country to participate in international seismicity monitoring schemes, for joint national and international research projects and collaborations and as an integral part of the integrated geohazard monitoring plan for Nigeria. Fig. 1 shows seismicity of Nigeria from 1933 to 2016, seismic stations and mapped suture zone in the country.

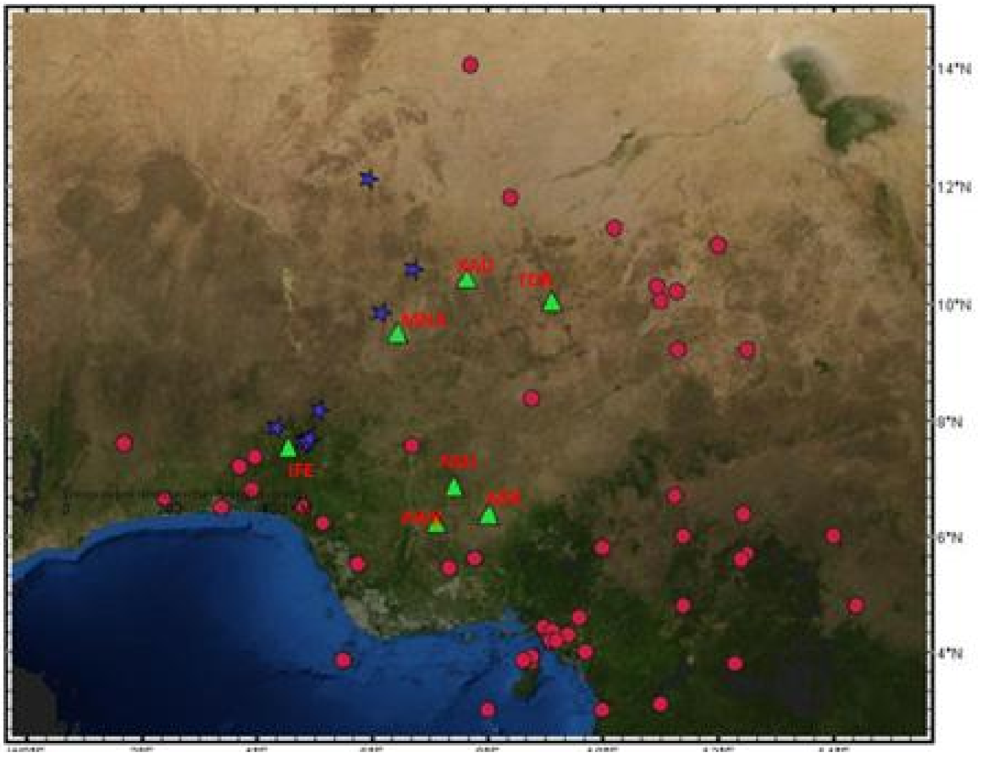


Fig. 1. Seismicity of Nigeria and immediate environs from 1933 to 2016. Red balls represent earthquakes; Green triangles denote stations and blue stars show the trending of Ifewera-Zungeru fault in Nigeria.

Table 1. Location of the operational and planned seismic stations [5,6]

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

Table 2. Characteristics of equipment at the respective stations [5,6]

Stations	Free Period	Damping rate	Generator constant	Digitizer Sensitivity	Sampling rate	Amplifier gain
Kaduna	16s	0.7	2000V/m/s	419,430C/V	40	0.0
Nsukka	30s	0.7	2000V/m/s	“	“	“
Toro	60s	0.7	2000V/m/s	“	“	“
Awka	16s	0.7	2000V/m/s	“	“	“
Ife	60s	0.7	2000V/m/s	“	“	“

Table 3. Properties of instrumentation at NNNSS [5,6]

Parameters	EP105 (Broadband)	SP400 (medium period)
Operating principle	Proprietary Electrochemical Sensors; force-balanced	Proprietary Electrochemical Sensors; force-balanced
Output signals	2 horizontal, 1 vertical; velocity flat response	2 horizontal, 1 vertical; velocity flat response
Output swing:	±20 V differential; (40 V p-p)	±20 V differential; (40 V p-p)
Dynamic Range	142 dB	142 dB
Passband	0.033 – 50 Hz	0.067 – 50 Hz
Generator constant	2000 V/m/s	2000 V/m/s
Maximum installation tilt	±10 °	±10 °
Mechanical resonances	none	none
Environmental	Waterproof, submersible (1m)	Waterproof, submersible (1m)
Temperature range	-12 to + 55 °C	-12 to + 55 °C
Housing material	Aluminum	Aluminum
Weight	~8kg	~8kg
Power	10-15 Vdc; (Nominal 12Vdc); 30 mA	10-15 Vdc; (Nominal 12 Vdc); 30 mA 12Vdc); 30mA

The Centre for Geodesy and Geodynamics (CGG) has been operating the Nigerian National Network of Seismographic Stations (NNNSS) since 2006, whose constituent stations are located as shown in Fig. 1. The properties of the respective stations (installed equipment) and geologic foundation are shown in Tables 1-3. The seismic stations are installed with broadband recorders. Broadband seismic equipment help to minimize some errors encountered while assessing signal from analogue sensors as demonstrated in [4]. The Awka, Abakiliki, Minna, Kaduna, Nsukka, Ife and Toro stations located in triangulation are currently operational while construction of Oyo, Abuja, and Ibadan stations is ongoing.

2. BRIEF GEOLOGY AND TECTONIC SETTINGS OF NIGERIA

Nigeria is located within the intraplate area, and its 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 [7]; Fig. 2. About two-thirds of Nigeria's landmass is underlain by the Precambrian basement complex consisting of gneisses, migmatites, schist, and various metamorphic rocks and granites, while the remaining one-thirds is made up of sedimentary rocks [8].

Basement Complex rocks outcrop in four main areas of the country: North of Rivers Niger and Benue, covering parts of Kaduna (likely in the vicinity of the Kaduna station), 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 Taraba State [2]. Sedimentary successions in these basins are of middle Mesozoic to Recent age [9]. Although not shown in Fig. 2, 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 [10]. Generally, Toro, Minna, Kaduna and Ife stations are located on the basement complex, while Awka, Abakiliki and Nsukka stations are sited on the sedimentary basin.

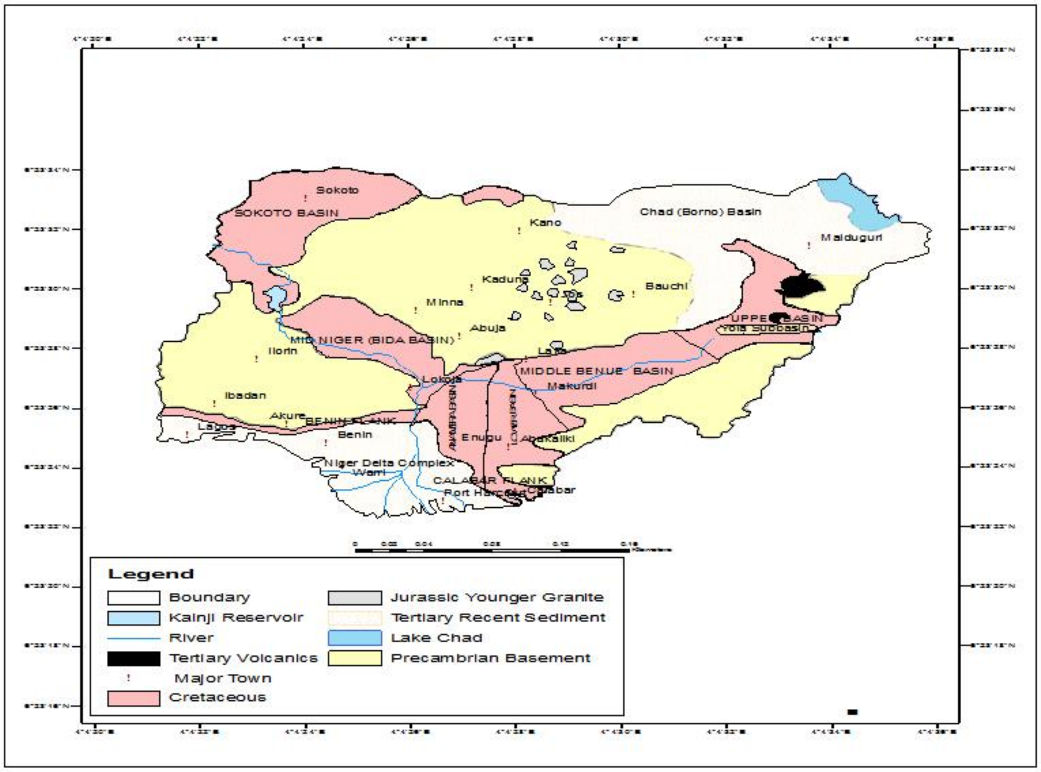


Fig. 2. Geological map of Nigeria, modified after [3]

The aim of this study is to carry out a preliminary evaluation on the performance of broadband stations in Nigeria, with special reference to Kaduna (KAD) and Nsukka (NSU) stations, using available techniques. These techniques involve seismic noise analysis, signal to noise ratio, the source of noise to stations, ambient seismic noise correlation and receiver function computations.

3. MATERIALS AND METHODS

The continuously recorded data from January to December 2010, from the stations in Nigeria, formed the database for this study. The long recording period is expected to account for the different noise variations. In order to discriminate the diurnal variations, daytime computations (one hour long each) were performed within 9.00am to 6.00pm and night computations from 8.00pm to 6.00am. The variation in noise patterns on the account of seasonal, geographic, geological and environmental differences was investigated. The desired length, time, day, week, month on the data were subsequently selected for analysis. Signal to Noise Ratios was computed from spectral analysis using Matlab to confirm the noise level at the respective stations. The straightforward procedure is presented in Fig. 3. Noise spectra were computed from one-hour long data segments from each station between frequency bands of 0.01Hz to 5.0Hz. Diurnal variations of seismic noise were conducted separately to investigate temporal variations. Possible sources of noise to the stations were estimated using data acquired from structured questionnaire and field work during this study.

For the component of noise correlations, noise analysis for KAD and NSU stations were performed using the Pascal Quick Look Extended (PQLX) software. Data were continuously recorded during 2010 for 1-year period. Power spectral densities were computed from one-hour long data segments from both stations. The location of the stations separated with approximately 400km distance is shown in Fig. 4.

A detailed description of the data processing procedure for the seismic noise correlation was adopted after [11] and illustrated in Fig. 5. The data were converted from mSEED to SAC format, resampled with one sample per second and 24-hour long data segments were constructed. The mean, trend, and instrument responses were then removed. Earthquakes and other disturbing effects such as instrumental irregularities were removed by applying temporal normalization in this stage. Additionally, spectral whitening was applied in order to remove the effects of microseism at double frequency (~7 sec) and single frequency (~14 sec) periods. Cross-correlations and stacking were performed daily in the frequency domain.

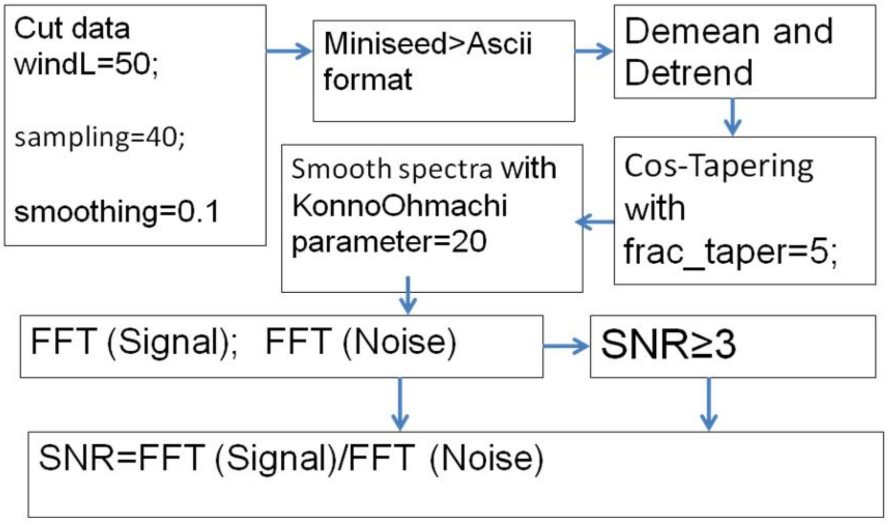


Fig. 3. Schematic procedures for signal to noise ratio computation

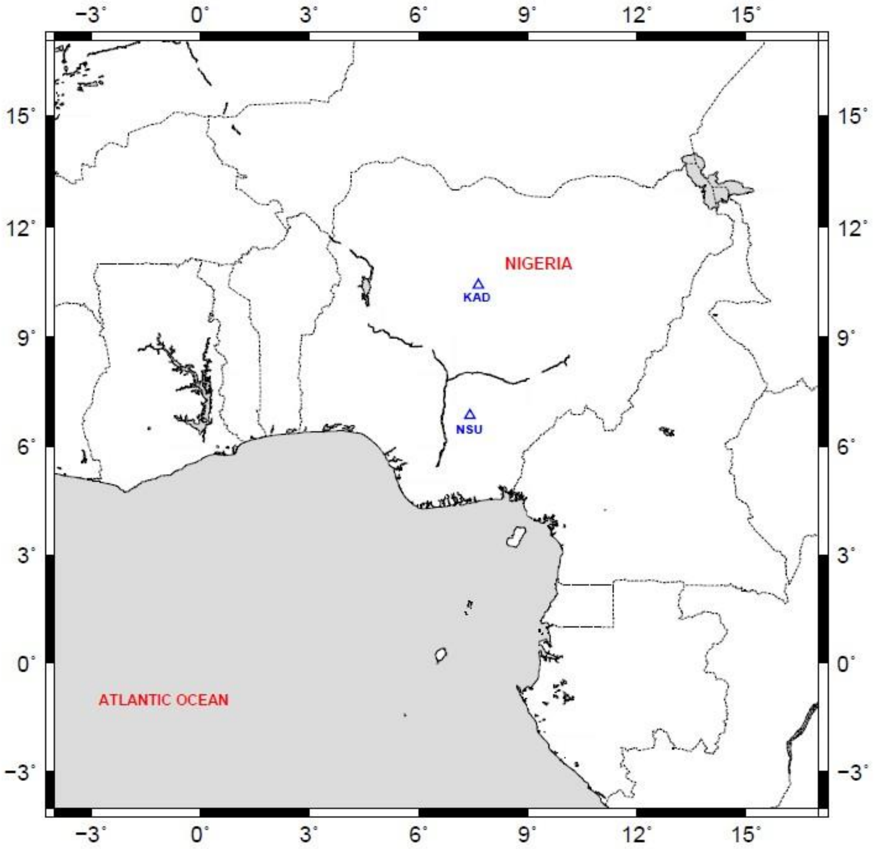


Fig. 4. Location of the stations Nsukka and Kaduna

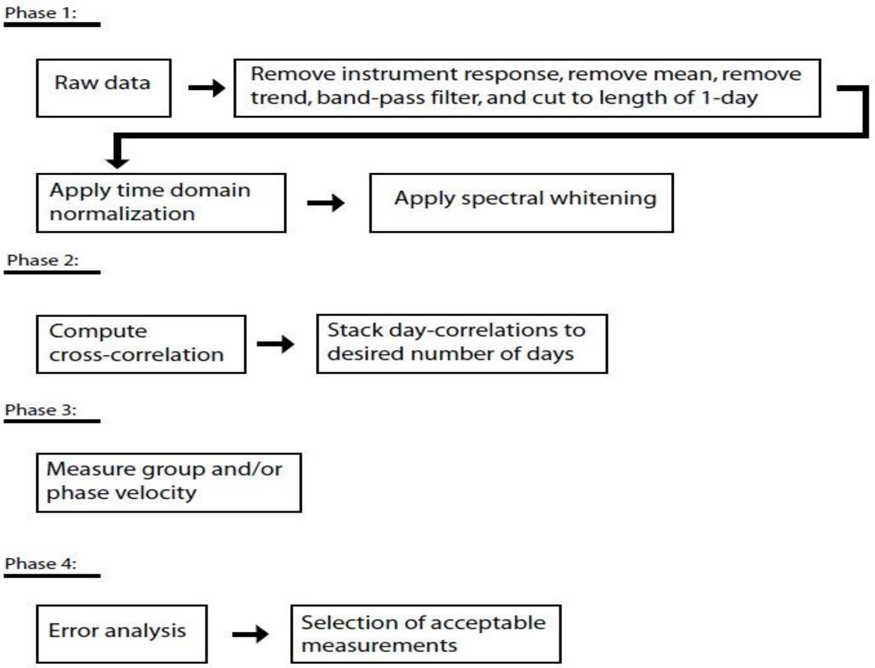


Fig. 5. Schematic representation of the data processing steps [11]

Similarly, for the receiver function computations, the teleseismic events at epicentral distances between 30^0 and 95^0 with magnitudes M ≥ 5.5 were extracted from the continuous data. But due to the low signal to noise ratio, only 25 of them were selected to compute the radial and transverse receiver functions. To compute the receiver functions, the selected waveforms were decimated to 20 samples per second, windowed between 30s before and 90sec after the P arrival, tapered, mean and trend removed. Both of the radial and transverse receiver functions were computed by rotating the horizontal components into the great circle path and deconvolving the vertical component from the radial components by using an iterative time domain deconvolution procedure similar to the one defined in [12].

4. RESULTS AND DISCUSSION

It was observed that the Nsukka station clearly exhibits significantly high noise level than the Kaduna station which makes computations of receiver functions at this station impossible. The high noise at Nsukka station could be as a result of noise amplification from soft soil, cultural and instrumental response. The magnitude spectral from Kaduna show strange abnormalities at low frequency regions.

Site and changes due to atmospheric factors like temperature or pressure and other environmental factors may also be responsible for some abnormalities observed in Kaduna station, as the station is located on the surface of bedrock without a vault. These findings are consistent with those documented in [13].

Findings from questionnaires and field investigations showed that the sources of noise to the stations include, wind on trees, human activities close to the stations; and ambient noise. Vehicular traffics and machinery, oil pipelines, geologic and instrumental noise may also be responsible for the observed noise.

Despite the differences in geographical locations of stations in Kaduna and Nsukka, high levels of cultural noise were observed on both stations. This may be due to human activities close to the stations, and other cultural influences like wind and vehicular traffic.

The signal to noise ratio (SNR) at Nsukka station (Fig. 6) is low but better at Kaduna station (Fig. 7). Factors ranging from possible noise amplification from site effect and contribution of short period sensor (16sec.) installed at the Nsukka station may be responsible for this. There might be other reasons, which could be investigated in the future. It is encouraged to enhance insulation around the sensitive equipment to take care of the noise resulting from effects of temperature, anthropogenic sources, pressure and other noise sources.

Fig. 8 showed the results of an attempt made to achieve tomography using operational stations in Nigeria. Tomography was not possible because of the large interstation distances as shown in table 4. However, with long period cross-correlation, it would be possible to evaluate average velocities along the stations' paths.

Results from seismic noise analysis using [14] showed that at KAD station, the noise level is high and the average noise level is above the high noise model in [15] at periods greater than 10sec (Figs. 9-10). This is especially apparent on both horizontal components. At NSU station the noise level is high at lower periods (<1sec) which may indicate the contribution of cultural noise or may be related to the instrument response correction (as the instrument response is poorly known). A problem with the BHN component of NSU station can be observed as the average of the spectrum is flat between 1-10sec. A more comprehensive noise analysis should be performed in order to understand the noise characteristics and the isolation of the both stations must be provided in order to obtain better data quality and high S/N ratio.

Table 4. Interstation distances in kilometers (Km)

	NSUKKA	AWKA	ABAKALIKI	KADUNA	IFE	TORO	MINNA
MINNA	313	371	388	95	302	299	0
TORO	401	478	425	167	574	0	299
IFE	325	318	405	467	0	574	302
KADUNA	397	469	451	0	467	167	95
ABAKALIKI	85	102	0	451	405	425	388
AWKA	77	0	102	469	318	478	371
NSUKKA	0	77	85	397	325	401	313

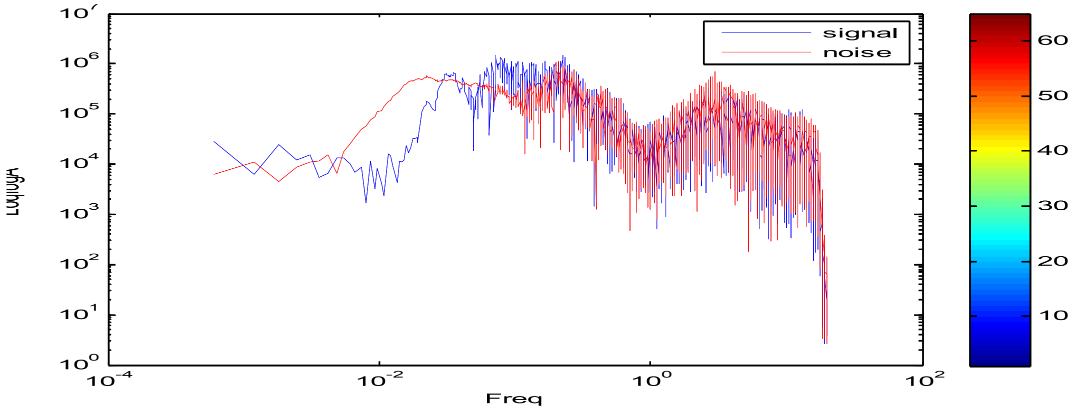


Fig. 6. Power spectrum from Nsukka station on a sedimentary basin (Red=noise; Blue=signal).

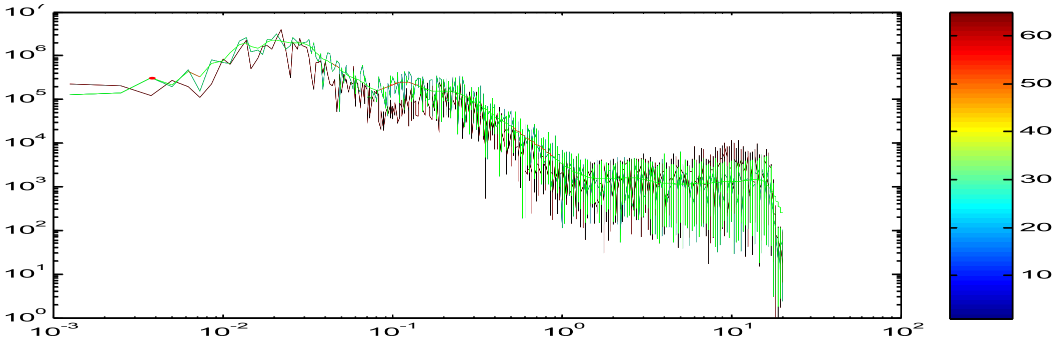


Fig. 7. Power spectrum from Kaduna station on a basement complex. (Green=signal; black=noise)

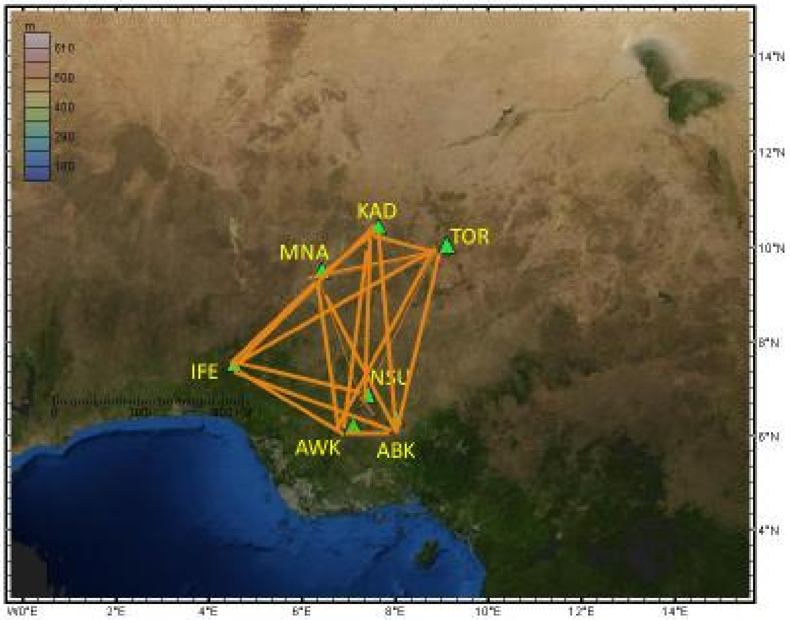


Fig. 8. Cross-correlation of ambient noise along possible station paths in Nigeria, with sparse paths coverage. (Green triangles represent seismic stations)

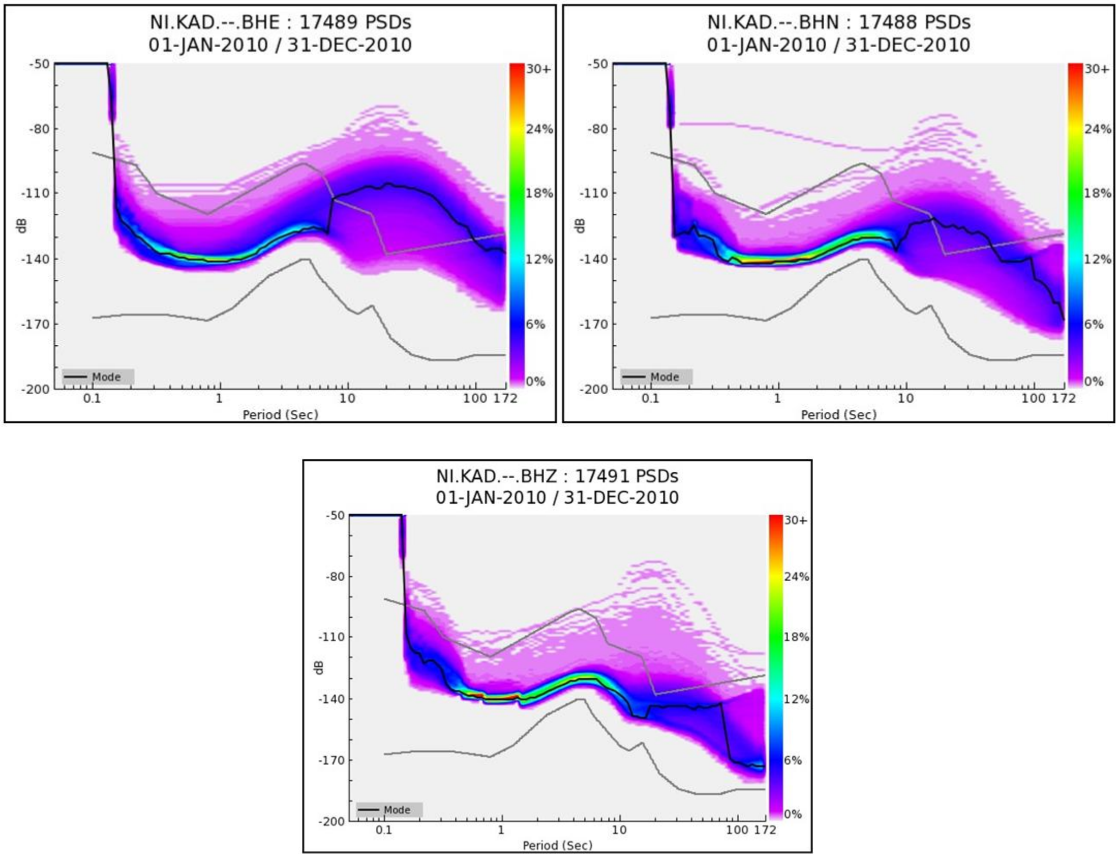
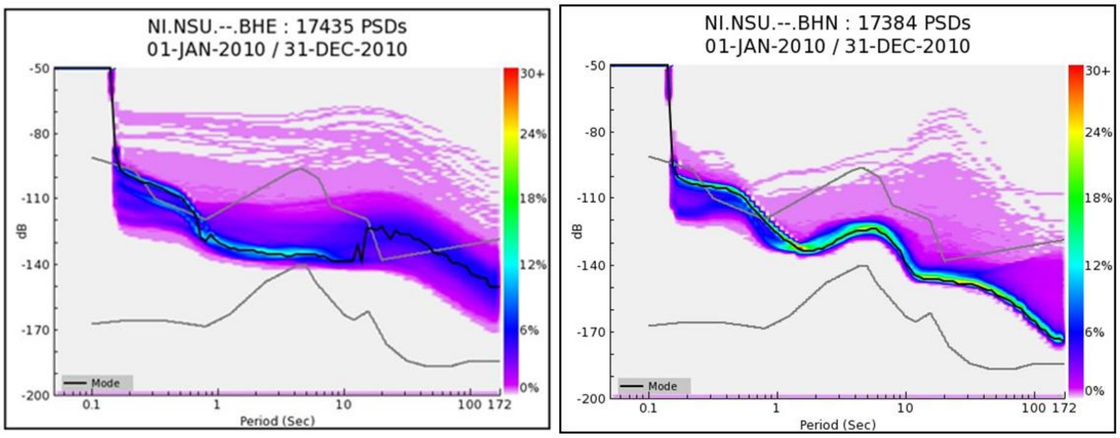


Fig. 9. Power spectral densities of KAD station for one-year data (BHE, BHN, BHZ components from top to bottom).

Results from ambient noise cross-correlation between seismic stations of Kaduna (KAD) and Nsukka (NSU) from the available continuous data of 2010, are presented in Figs. 11 to 15. Fig. 11 shows the cross-correlations between KAD and NSU stations. Each trace shows a one-month stack of correlations and the trace at the top (13) shows the final stack of 12 months. The correlations are antisymmetric indicating the noise sources are non uniforms. It is also apparent the seasonal variations of the noise observed on the monthly correlations (Figs. 11-12).



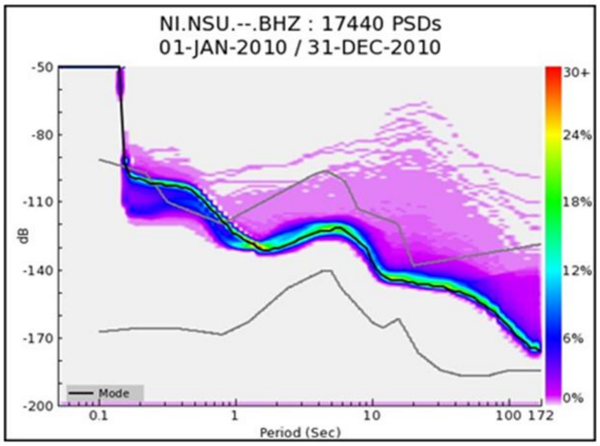


Fig. 10. Power spectral densities of NSU station for one-year data (BHE, BHN, BHZ Components from top to bottom)

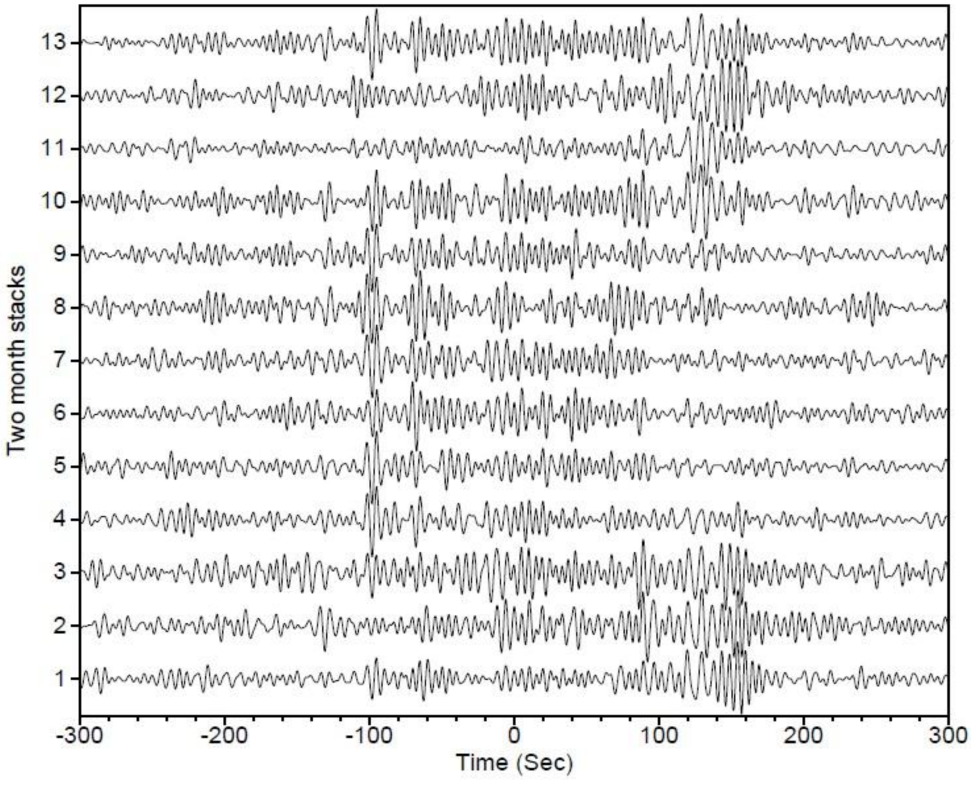


Fig. 11. Cross-correlations for the vertical components of KAD and NSU stations with interstation distance of 398 km and filtered in the 5-10 sec period band. Each trace represents one month of stack and the trace 13 is the stack of 12 months. The traces are normalized with their maximum values

In the same vein, Radial and transverse receiver functions for KAD station are shown in Figs. 16 and 17. The NSU station did not provide sufficient number of receiver functions. The H-k stack performed using 25 receiver functions of KAD station did not show a clear Moho conversion beneath the station, and the results obtained from the H-K stack are poor.

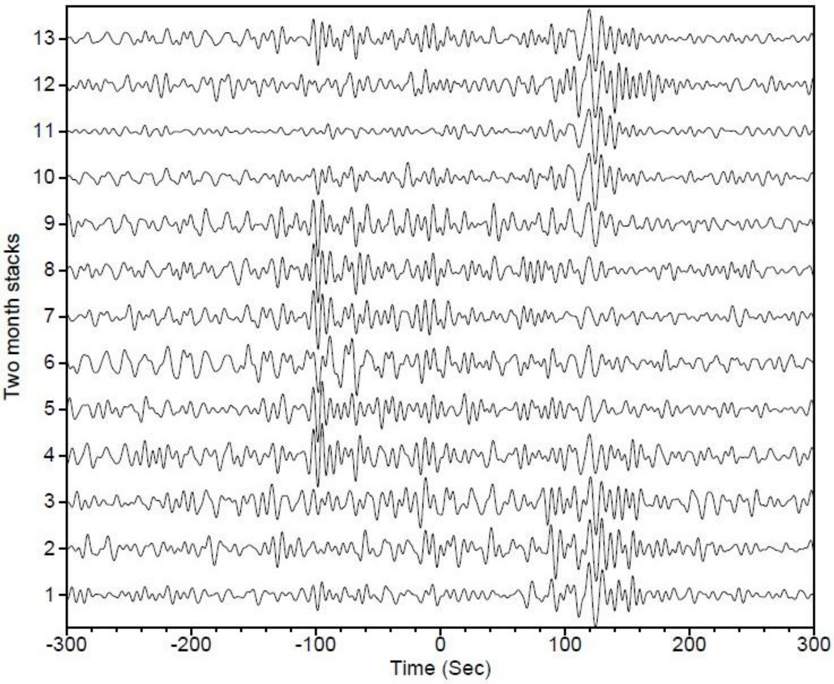


Fig. 12. Cross-correlations for the vertical components of KAD and NSU stations with interstation distance of 398 km and filtered in the 6-16 sec period band. Each trace represents one moth of the stack and the trace 13 is the stack of 12 months. The traces are normalized to their maximum values

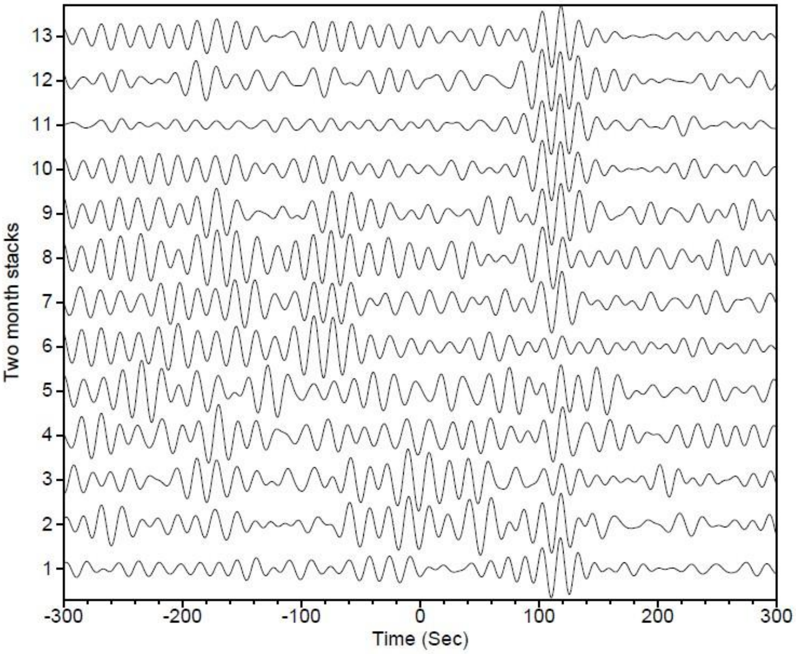


Fig. 13. Cross-correlations for the vertical components of KAD and NSU stations with interstation distance of 398 km and filtered in the 15-25 sec period band. Each trace represents one moth of stack and the trace 13 is the stack of 12 months. The traces are normalized with their maximum values.

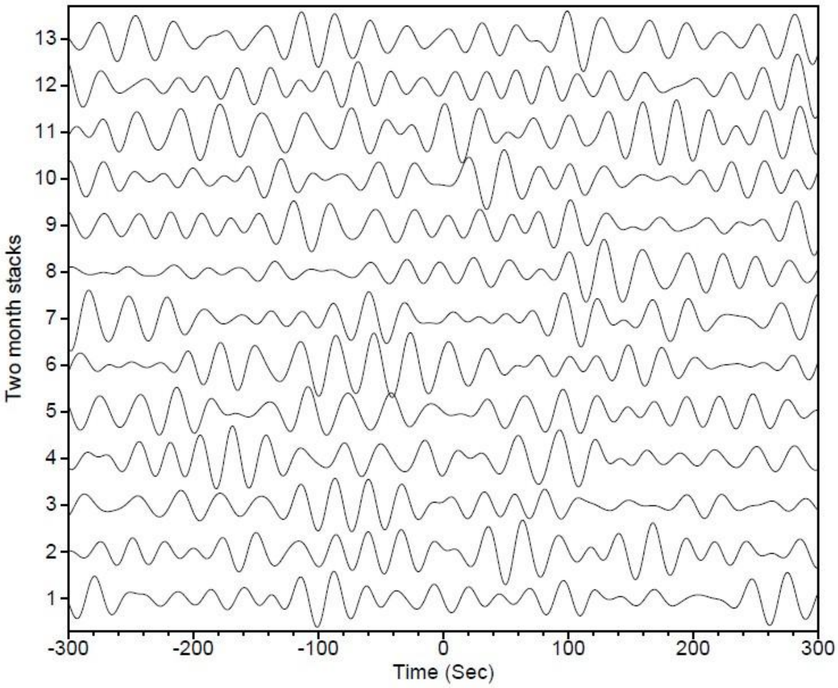


Fig. 14. Cross-correlations for the vertical components of KAD and NSU stations with interstation distance of 398 km and filtered in the 25-35 sec period band. Each trace represents one moth of stack and the trace 13 is the stack of 12 months. The traces are normalized with their maximum values.

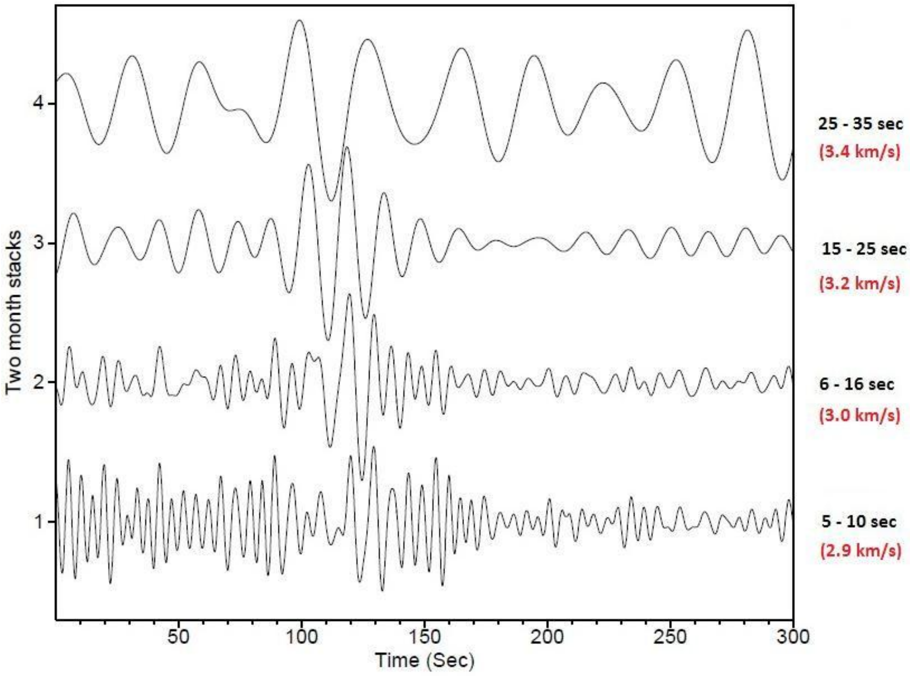


Fig. 15. One year stacked long cross-correlations of KAD and NSU stations for the vertical components with an interstation distance of 398 km and filtered at different period bands.

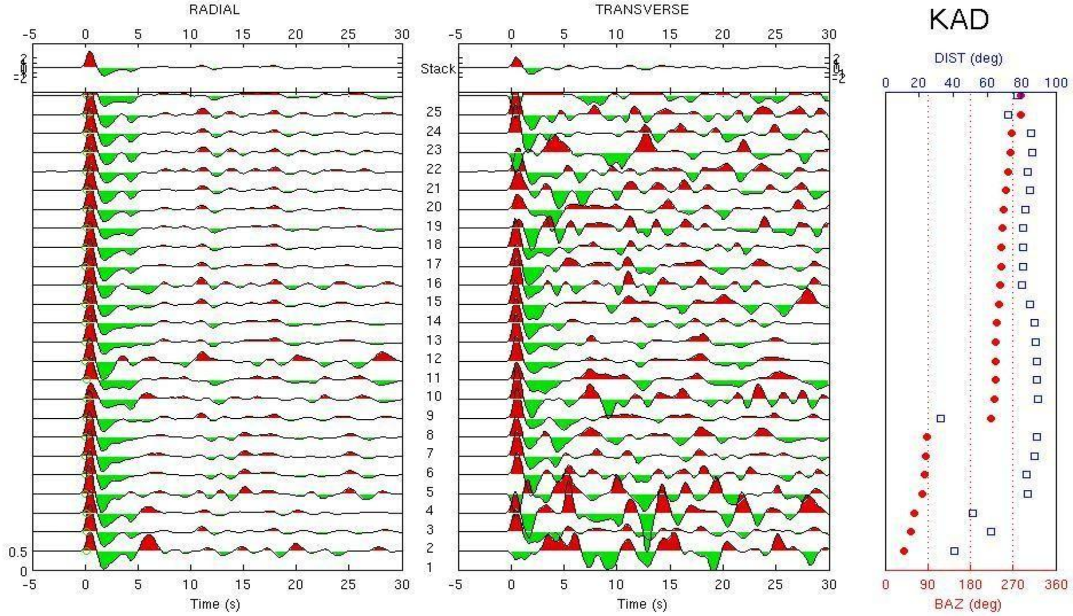


Fig. 16. Radial receiver functions, transverse receiver functions and variations with respect to distance and back-azimuth.

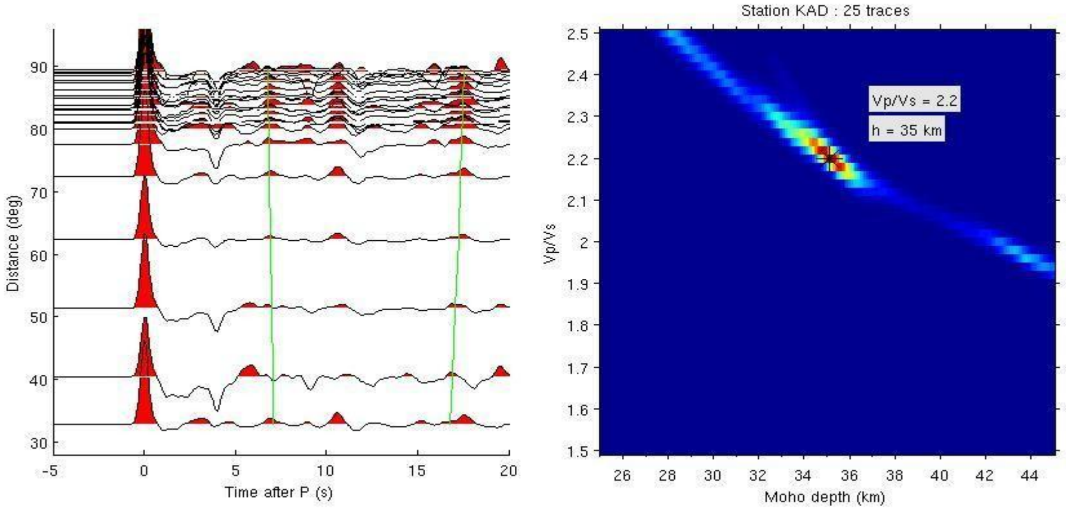


Fig. 17. H-k stack of the receiver function at KAD station

5. CONCLUSION

The preliminary evaluation of the performance of the broadband seismic stations with special reference to the stations at Kaduna and Nsukka has been carried out, to give an overview and data reliability of the seismic network infrastructure in the country. From the noise analysis, high noise levels were observed at Kaduna and Nsukka stations but higher at Nsukka station which is likely due to a number of factors, ranging from contributions of cultural noise to the installed short period sensor and instrument response correction. The possible sources of noise to the stations include wind on vegetation, human activities and machinery, oil pipelines and vehicular traffic.

Although tomographic study was not possible using all the operational stations in Nigeria, cross-correlation between Kaduna and Nsukka stations shows that the correlations are antisymmetric; which indicate the noise sources are non-uniform. The results of radial and transverse receiver functions for both stations show that NSU station did not provide a sufficient number of receiver functions, and the H-k stack performed using 25 receiver functions of KAD station did not give a clear Moho conversion and as the results obtained from the H-K stack are poor.

While the results presented in this study are only a preliminary evaluation that requires performance of more comprehensive analysis, it is however recommended that the stations should be better installed and insulated to improve SNR. The orientation and levelling of the instruments should be checked. The standard processing techniques (Correlation, Receiver functions) could give all-around reliable results using data from the stations. It is also pertinent to replace the short-period sensors at the stations with long-period sensors in order to minimize noise.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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