COMPARATIVE AMBIENT NOISE ANALYSIS USING PROBABILITY SPECTRAL DENSITY OF BANGKA SEISMIC NETWORK

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Received: 18-01-2023
Revision Received: 20-01-2023
Accepted: 10-05-2023

DOI :
10.17146/jstni.2022.23.2.6788

Keywords: Ambient noise, Power Spectral Density (PSD), Probability Density Function (PDF).

Abstract Concerning the NPP seismic hazard investigation, continual operation of seismic monitoring stations required consistent performance and a good quality of data. Here we investigate the performance level of four micro-earthquake stations in Bangka Island by presenting the identification and analysis of ambient noise characteristics. The analysis was performed using the Probability Spectral Density (PSD) method available in Obspy python-based library. As the performance benchmark, we utilized the New High Noise Model (NHNM) and New Low Noise Model (NLNM) of Peterson (1993) and McNamara & Bulland (2004). Analysis was also performed by comparing the 2021 and previous studies using 2014 data. With the exception of MTK station, at the period range of 0.1-1 sec, most of the station exhibits good performance. The noise level at periods 1-10 sec developed a low probability occurrence noise level and decreasing energy along with higher periods which strongly correlated to the micro-seismic activity. Abnormal noise levels at period range larger than 10 sec in 2014 data were identified and 2021 data showed that sensor replacement has effectively reduced these noise levels.

INTRODUCTION

Safety aspects related to reliable seismic hazard assessment of a nuclear power plant (NPP) site are of great importance(1). Installation of local seismic monitoring network is needed to evaluate both seismic hazard and risk(2). According to the International Atomic Energy Agency's (IAEA) guidelines on seismic hazard evaluation and monitoring, the local seismic network should be installed long enough in order to acquired detailed information of potential seismic sources of the site(2,3).

Seismic monitoring in Bangka and its surroundings had been carried out from 2011 to December 2021 by previously known as National Nuclear Energy Agency (BATAN). Initially, the seismic network consisted of ten stations and was later reduced to seven stations starting in 2017. Research on seismic hazards in Bangka island has been performed using the recorded seismic data coming from the seismic network, such as (4) and (5). Nevertheless, prior to the seismic data utilization, it is significant to have a performance evaluation of the installed seismic network to ensure the quality of the resulting seismic data(6).

Previous studies on ambient noise analysis of the Bangka Island seismic network were performed by (7) and (8) using data recorded from March up to December 2014. At that time, the installed seismometers were the GeoSig VE-53 broadband seismometers. But since 2016, gradually the seismometers were replaced by using Lennartz LE-3Dlite mkii, a short-period type.

A total of seven seismic monitoring stations were placed on Bangka Island, namely Jebus (JBS), Muntok (MTK), Tempilang (TPG), Nangka (NGK), Sebagin (SBG), Toboali (TBA), and Sungai Liat (SLT) (Figure 1). In this study, only four stations were used, namely JBS, MTK, SLT and NGK as shown in Table 1. The other two stations could not be used in this study because the sensor devices were not in operating condition. The "QT" code preceded before the station code was referred to the Quanterra equipment system installed in 2016. Different code was applied at the seismic equipment installed before 2016. For 2014 data, the station code was preceded by "BN" code.

Table 1. Bangka Seismic monitoring Stations code, location and coordinate

Station code	Station Location	Longitude (°E)	Latitude (°N)
QT.JBS	Jebus	105.44	-1.59
QT.MTK	Mentok	105.12	-2.01
QT.SLT	Sungai Liat	106.11	-1.8
QT.NGK	Nangka	106.39	-2.62

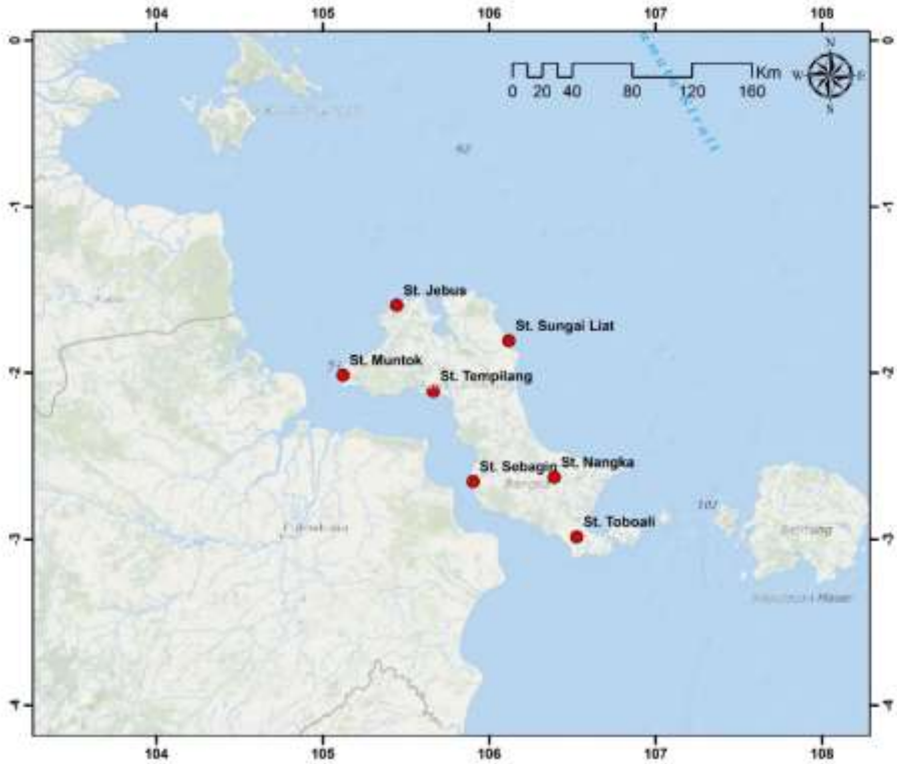

Figure 1. Micro-earthquake observation stations in Bangka islands.

The objective of this paper is to investigate the performance level of four micro-earthquake stations in Bangka Island by presenting the identification and analysis of ambient noise characteristics. To be considered as a good performance seismic station, the noise level at every period range should be within the New High Noise Model (NHNM) and New Low Noise Model (NLNM) which was developed by (9) and (10). The analysis was also performed by comparing the resulting PSD of the previous study (8) and the newer one of September 2021 data. We utilize the PSD method in acquiring the performance level of each station(10). The PSD method has been used widely as an efficient approach to analyze and asses seismic networks (10–15). The result will be important for the validity of seismic recorded data that will be used for further seismic hazard analysis.

EXPERIMENTAL SECTION

Instrumentation

The September 2021 data was recorded using a Lennartz seismometer which was connected to the Quanterra Q330 data logger. This equipment uses seismic data that propagates from 3 components, namely the vertical component (Z), the north-south component (N-S), and the east-west component (E-W). The Lennartz seismometer uses a 12V input using a current of less than 7.5 mA with an output of 3 analog voltages. The Lennartz seismometer has a sensitivity of 0.13e+01 with a polishing value of -0.4442 to 0.4442 and a gain value of 0.419(16). Then, the Lennartz seismometer was chosen because it has several advantages, including; (1) a powerful instrument, (2) very easy to install, and (3) uniform sensitivity and capability of capturing up to 50Hz frequency(17).

Based on these specifications, the Lennartz seismometer can capture small earthquakes around the earthquake observation area which can be used as recommendations for results regarding seismic activity on the island of Bangka as a site study of nuclear power plants in Indonesia.

Methods

Power Spectral Density (PSD)

PSD is a method used to measure background noise in seismic data. PSD uses the Fourier transform or fast Fourier transform (FFT) of the original data to streamline calculations (10,18). PSD uses an algorithm from the Albuquerque Seismological Laboratory which has found new developments, namely the new low noise model (NLNM) and new high noise model (NHNM) (9,10,19,20). PSD starts from the periodic time Fourier transform equation (Eq. 1).

$$Y(f,T) = \int_0^{T_r} y(t)e^{-i2\pi ft}dt \qquad \text{Eq.1}$$

The equation is derived using a frequency estimate with a value of the number of Fourier Transform, *nfft* = (N/2)+1=16385. Then, the PSD process is repeated for each of the overlapping time segments in hours. After the segments are calculated, the energy will be averaged where each time segment has a time length of, T_r. So, the PSD time equation is shown in Eq.2(21). By using the NLNM and NHNM algorithms (Figure 2), the final PSD equation is shown in Eq.3(21).

$$P_k = \frac{1}{q}\left(P_{k,1} + P_{k,2} + \cdots + P_{k,q}\right) \qquad \text{Eq.2}$$

$$P_k = 10 * log_{10}(P_k) \qquad \text{Eq.3}$$

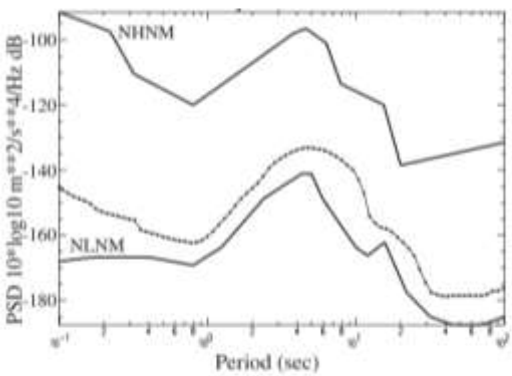

Figure 2. The new low noise model (NLNM) and new high noise model (NHNM)(10)**.**

To find the average energy from the initial period to the end period, we used the Probability Density Function (PDF). The averaging process continued every hour once a PSD was estimated, then generate a PSD estimate for each station component. Energy will be accumulated in 1 dB intervals to produce a graph of the frequency distribution (10).

In order to visualize the probabilistic spectral densities, we used the Obspy python based library (22). It is an open-source tool that has been developed since 2010. The calculations provided at Obspy library are based on the routine used by McNamara (2004) (10). We used the data recordings from each station in the form of mini-SEED and the sensor specification (gain, poles and sensitivity) as the data input.

Seismic Noise categorization

Based on its source, seismic noise can be categorized into cultural noise, earthquake, and artifact system (10). The most common noise in seismic is cultural noise. These sources come from human activities or phenomena that exist on the earth's surface. Cultural noise is at high-frequency at ground level (0.1-1 sec) (10). Cultural noise can be reduced in several places, including drilled holes, deep caves, and tunnels. Cultural noise can be found in PDF if there is a low probability occurrence at high frequency (10).
Instead of removing the earthquake signals from the data, we adopt the approach introduced by McNamara (2004) to include all input signals including the body and surface waves from an earthquake(10). One of the advantages of this approach is to obtain information about the probability of obscured teleseismic signals by various noise sources. Earthquake signals commonly have low-probability occurrence when the magnitude is small compared to the ambient conditions around the observation station (23).

The last category of seismic noise is the artifact system. This kind of noise usually resulted due to telemetry dropouts, automatic mass recentres, and sensor glitches. The main characteristic of the artifact system is high-power, low-probability noise levels in the PDF plots (23). Some of the artifacts in the PDF are easy to explain and can be used by operators on certain networks.

RESULTS AND DISCUSSION

To assess and compare the quality of the seismic network of 2014 and 2021, PSD plots were computed using continuous recording with

PPSD class of ObsPy. A comparative plot of 2014 and 2021 PSDs are shown in Figure 3. Each plot includes the minimum, maximum, mode, and top and bottom percentiles of the obtained PDFs. The upper black solid line displayed the New High Noise Model (NHNM) while the lower solid black line showed the New Low Noise Model (NLNM). The PDF percentage is expressed with the color scale on the right side. The PDFs of 2014 data were constructed using 6671 segments(8), while the September 2021 data PSDs were constructed using 1438 segments of PSDs.

In term of seismic station location, the location of MTK station was relatively far from the main road, but near to the road access of oil palm truck and public settlement. Both JBS and NGK stations were located near the main road, which means there was a noticeable traffic rate around the station. The JBS station was near the main road to the mining area, while the NGK station was located next to the plantation road access. On the other hand, the SLT stations were located far from the main road and public settlement. All the seismic stations were positioned at a distance range of 500-750 m to the coastline, except for the NGK station which was located more than 2 km from the coastline.

Human activities in general would generate noise of the high frequency or short period characteristics with a period value of less than 1s (24). stations that are close to main roads or roads with high traffic, residential areas, tourist areas, plantation and mining areas and others, in general would have a higher noise level in short period range. The long period noise characteristics with a period value of higher than 20 s in general would be associated with seismic hum which was excited from natural sources such as ocean infra-gravity waves, sea waves or wind (24,25).

The MTK station was located near the public settlement and plantation road access. This noise range is identified as the cultural noise associated with higher human activities because the station site had changed demographically compared to the 2014 situation. This condition clearly affected the low period noise with a period of less than 0.5 s as shown in Figure 3 (b). The noise level in this period range is relatively higher than other frequency range with an amplitude of -110 to -80 db, but the level is still below the NHNM values.

The JBS and NGK stations were located near the main road. However, despite the similar surrounding condition, the low period noise characteristics patterns were quite different. The noise level in the JBS station was constantly high from period of 1 s to 0.1 s. On the other hand, at the NGK station, the noise level started to get higher at the period of 0.2 s to 0.1 s. This condition indicates that the mining and settlement activity near the JBS station was clearly more active than the plantation activity near the NGK stations in this period of time.

The SLT station low period noise level was quite different with the other stations. The noise level in this station was noticeably lower. This condition indicates that the road near the station may have low traffic which lead to less cultural noise in this area.

With the exceptions of the MTK station, we found that the noise levels recorded during September 2021, at the period range of 0.1-1 sec and >10 sec, fall within the NHNM and NLNM levels (see Figure 3(d,f,h)). Discrepancies were observed for the 2014 data (see Figure 3(a,c,e,g)) at a period larger than 10 sec where the average noise levels surpass the NHNM level. These high levels of noise could be associated with the installation problem of the equipment systems(26). By looking into the 2021 data, system and sensor replacement in 2019, proved to be effective in handling these types of noises.

As shown in Figure 3(b), between the period of 0.1 to 1 sec, at the MTK station, the noise levels exceed the NHNM envelope which showed a different pattern from the previous study (7,8) shown in Figure 3(a). The noise variation range at the MTK station in 2021 was 20-40 dB higher when compared to the data resulted in 2014.

At the period range of 1-10 sec, all stations exhibited a strong variation of low probability occurrence noise levels up to 30 dB which tend to decrease along with a larger period. The noise level variations at periods 3-6 sec fall lower than the NLNM level. This period range was associated with the microseism characteristics period (24) which indicates that the natural microseismic noise characteristics of Bangka Island are generally below the NLNM values.

Studying the noise energy around the period 1.28 sec showed that for all of the stations, the noise levels are 10–20 dB higher than that of the NLNM. This period range is particularly important for stations located in the coastal line (27). Oceanic wave energy could somehow interfere with the recorded seismic data at a period range of 1-10s(27). Since all the selected stations were located within a 5 km radius of the coastal line, then these peak noise levels in the period of 1.28 sec were understandable.

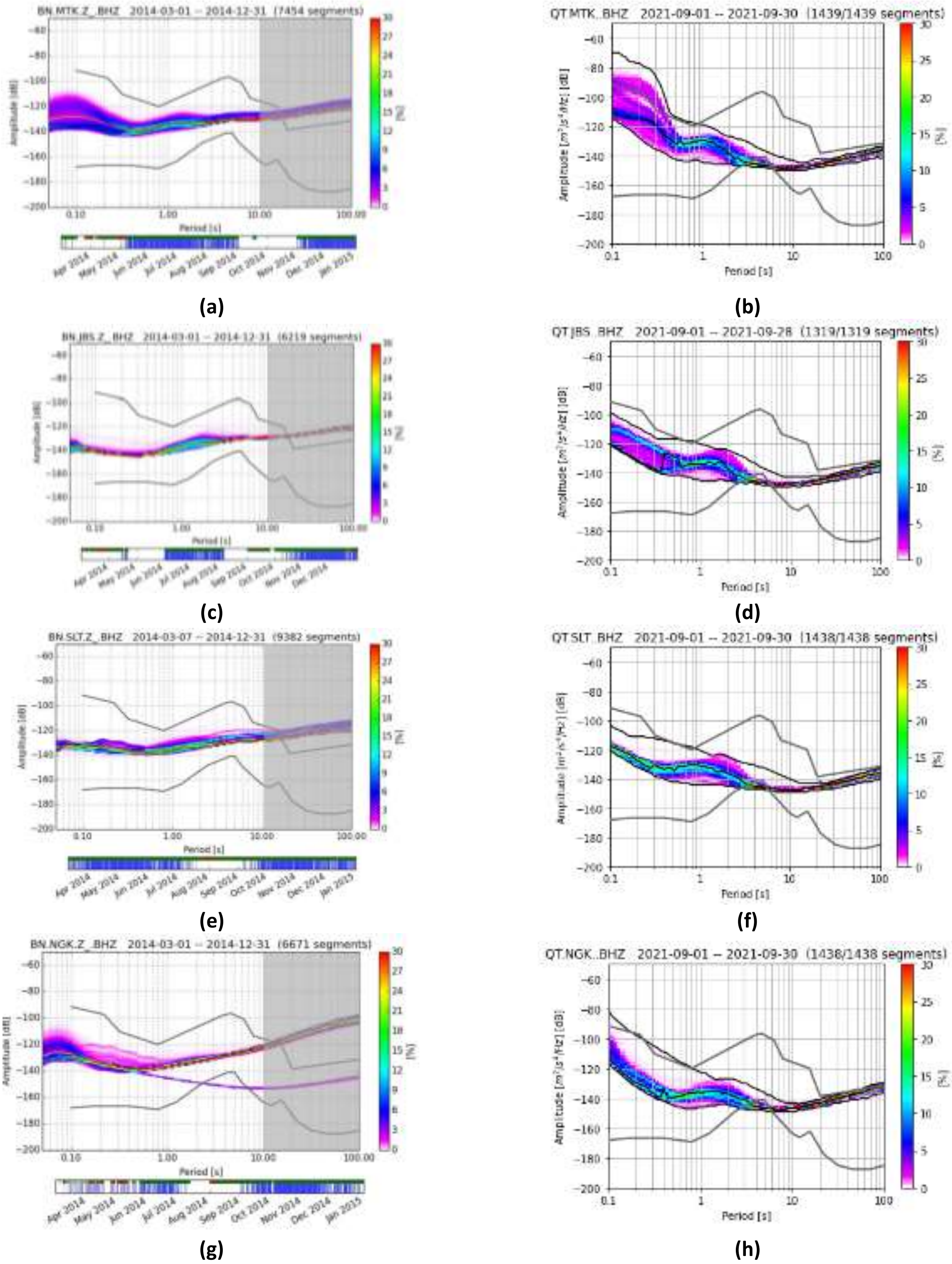

Figure 3. Power spectral density curves for station (a) MTK-BHZ March-Dec 2014(8);(b) MTK-BHZ September 2021;(c)JBS-BHZ March-Dec 2014(8); (d) JBS-BHZ September 2021;(e) SLT-BHZ March-Dec 2014(8); (f) SLT-BHZ September 2021; (g) NGK-BHZ March-Dec 2014(8);(h) NGK-BHZ September 2021.

The seismic network at the NPP site is used to detect local and regional earthquake events. This earthquake event analysis will later be used further at the probabilistic earthquake hazard analysis stage to ensure the safety of nuclear installations and society in general. Poor performance of the seismic network will make it difficult for the earthquake event identification process because the results obtained will be biased and ultimately reduce the accuracy of the seismic hazard analysis of the intended site. One measure used in measuring the performance of seismic networks is how the signal and noise ratio contained in the seismogram recording. The more noise contained in the seismogram recording, the lower the performance level of the seismic network.

The results of the analysis showed that 3 out of 4 stations showed good performance. However, limitations in the seismic recording periods do not provide a comprehensive picture of the level of ambient noise at each station.

The determination of seismic network placement greatly influenced the level of ambient noise recorded. In addition, the installation and maintenance of recording instruments were also important. Therefore, we recommend surveying the surrounding environmental conditions including but not limited to geography, topography, geology, demographic projections, road access, and climate. Geography, topography, and geological conditions are closely related to the identification of earthquake sources and the type of rock where the stations are located. It must be ensured that each station is placed on a type of hard rock. In the case of the Bangka seismic network, the station had been placed on hard rock and comply with other geography, topography, and geological requirements. However, demographic developments have caused some seismic station sites to no longer to be ideal.

CONCLUSION

In this paper, we analyzed recordings collected during September 2021 from the local seismic network of Bangka Island to characterize the noise and evaluate the performance of each site. Analysis was performed by comparing the 2021 data and previous studies using 2014 data. Seismic stations with noise levels within the NHNM and NLNM are considered to have a good performance or quality of data. At the period range of 0.1-1 sec, most of the station exhibits good performance, except the MTK station which yields low probability occurrence noise with high power exceeding the NHNM level. The noise level at periods 1-10 sec developed a decreasing pattern with higher periods and a strong variation of low probability occurrence noise which strongly correlated with the micro-seismic activity. Detailed analysis in this range of period, using cross-correlation with the oceanic and wind data is needed to have a more comprehensive understanding. The 2014 data showed an increasing noise level at a period larger than 10 sec which correlated to the instrumentation problem. The sensor replacement has effectively diminished the noise level which was shown in the 2021 data. Based on the different characteristics of ambient noise between 2014 and 2021 data, we can conclude that instrument and site conditions in terms of demographics play an important role in the characterization of seismic ambient noise.

In this study, we have a limited period of recorded data which caused difficulty in evaluating the seasonal or diurnal variation of seismic noise or the long-period seismic noise. Thus, for further investigation, we recommend utilizing a longer seismic record with a minimum recording period of one year. We also recommend cross-referred the climate data to have a comprehensive analysis of the ambient noise.

ACKNOWLEDGEMENTS

The authors would like to thank the Geophysics Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada for the cooperation under the Bangka seismic monitoring project. We would also like to thank the Institute of Technology of Sumatra for the chance to collaborate. Dima Agusdiansyah, Yuliastuti and Theo Alvin Ryanto are the main contributors to the article, while Akhmad M. Haifani and Nurlaila are the secondary contributor.

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