

Statistical properties of urban noise – results of a long term monitoring program

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ABSTRACT

High levels of noise pollution in urban areas have a detrimental effect on the health and quality of life of the affected population. Variations in environmental noise levels generally represent a random process affected by multiple factors. Apart from temporal noise variations, substantial differences in the noise pattern may be augmented by multiple factors that can be expected in a complex urban environment. However, there are some generic patterns and statistical characteristics that can be extracted from long term data. This paper analyses common features of sound pressure time histories and frequency spectra using a data set collected over 12 months at different urban locations. It is shown that sound pressure level (SPL) magnitudes do not follow a normal distribution, however several night time samples can be considered “almost normal”. A-weighted and C-weighted noise levels were shown to be highly correlated throughout the monitoring period for all monitoring locations.

Insights into the frequency content indicate a strong correlation between its neighbouring 1/3 octave levels and with wider frequency groups. Several spectral components were highly correlated with A- or C- weighted SPLs or both. The apparent similarity of noise variations and spectral content between monitoring locations highlights an opportunity to derive a normalised generic spectrum for the entire area. This can be used for modelling, noise prediction and facilitating effective urban noise planning solutions.

1 INTRODUCTION

Noise impact in urban environments is a very important issue that requires the attention of both the public and planning authorities. Excessive amount of noise exposure can lead to poor quality of life and will have detrimental effects on the health of the affected population. There are several factors that may lead to the increase of noise exposure within the urban environment such as the densification of the population which may lead to an increase in urban traffic and other associated activities within such areas. With a higher fraction of the population envisioned to be exposed to high noise levels, it is necessary that noise control measures are undertaken at the early stages of urban planning to minimise such impacts.

South Australia’s Environment Protection Authority has conducted a strategic noise monitoring project within the Adelaide central business district (CBD) over approximately 12 months. A substantial amount of data was collected from 6 monitoring stations and is available for a consequent analysis (Lenchine, Song 2017).

Six Bruel and Kjaer Type 3639 monitoring stations were deployed at several locations in the northern part of the Adelaide CBD. Locations of the monitoring stations were selected based on several factors, with the proximity to major noise sources such as arterial roads and entertainment venues being the decisive factor in the selection. These monitoring stations were also equipped with compact weather stations to identify local weather conditions such as wind speed and precipitation.

The conclusions in this work are based on data collected for 15 minute intervals unless another period is mentioned. The integration period was selected based on the basic regulatory document used in South Australia (*Environment Protection (Noise) Policy*, 2007). Typical data rectification procedures were applied to the original data sets, e.g. data collected over periods with rain or with wind speeds above 5m/s were disregarded. Time stamp of the presented data corresponds to the beginning of the data collection period, e.g. 8am time stamp for hourly data means that the noise estimates are reported for 8am to 9am period.

2 STATISTICS OF SOUND PRESSURE LEVELS

Overall sound pressure levels (SPLs) are major parameters used in assessing noise impact. A-weighted SPL is a widely used descriptor for environmental noise applications. This is also sometimes supplemented by C-weighted estimates to allow for additional post-processing. Analysis of large amounts of data show that there are qualitative similarities of SPL changes within urban monitoring locations (Lenchine, 2017). Figure 1 shows the average standardized hourly time history of the overall SPL data collected over a 12-month period from all monitoring stations. The hourly energy average for each of the monitoring locations was first standardized to the overall arithmetic average using the standard deviation of the data set:

$$Z_{i,j} = (L_{i,j} - \bar{L}_j) / \sigma_j \quad (1)$$

where $Z_{i,j}$ is the Z-score of i -th hourly SPL estimate for j -th monitoring location, $L_{i,j}$ is the energy average SPL, \bar{L}_j is the overall arithmetic average for j -th monitoring location and σ_j is the standard deviation computed for j -th monitoring location, $i=1,2\dots24$, $j=1,2\dots6$.

The hourly Z-scores were then arithmetically averaged between estimates computed for each of the monitoring locations. Z-score represents the collected data measured in units of standard deviation from the mean of a data set. As an example for Figure 1, the L_{Aeq} levels for 12AM was on average -0.5 standard deviations from the mean of the dataset. This allowed for a fairer comparison between monitoring stations with different overall average noise levels and data scattering. If the hourly energy average of each monitoring stations were considered before standardization, the monitoring location with the quietest locality would be rendered irrelevant by the calculations.

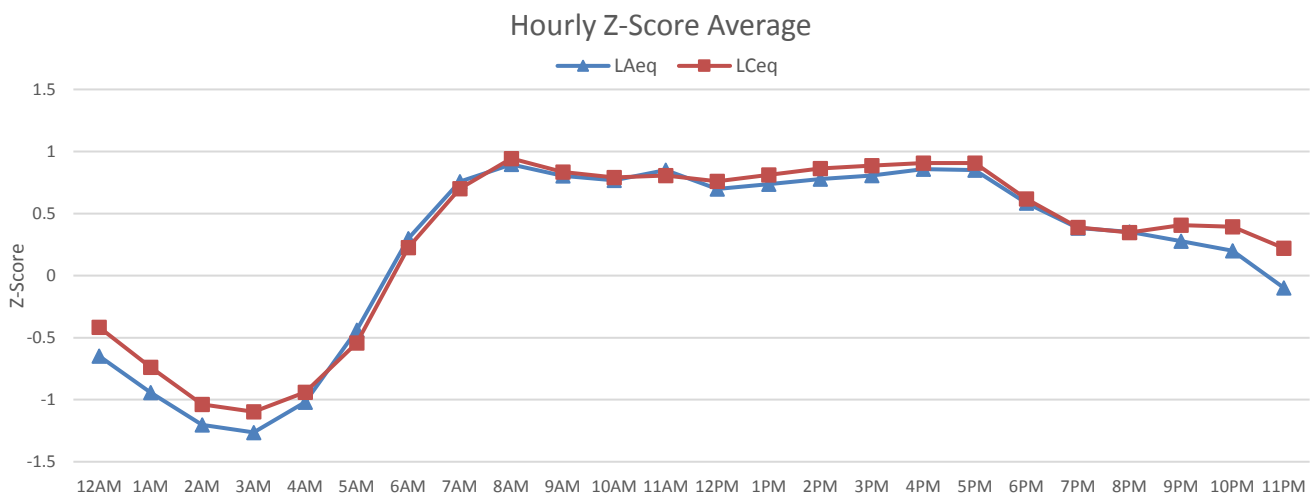


Figure 1: Average hourly time histories of the Z-Scores of A-weighted and C-weighted SPLs

Figure 1 shows time histories where early morning hours between 2 am and 4 am were generally the quietest periods of the day. Maximums at 8am and 5pm would generally correspond to traffic volume peaks during morning and afternoon rush hours. The standardized L_{Ceq} chart is also included in the figure and shows an additional local maximum at 9pm to 10pm. One can note that both L_{Aeq} and L_{Ceq} values in the figure show a very similar trend. Correlation between A-weighted and C-weighted SPLs and other acoustic descriptors is discussed in Section 3.2 (Table 3).

To further explore the statistical properties of urban noise, the data was separated into different evaluation periods: day, night and 24 hours. These periods are defined within this paper in accordance with the regulatory recommendations (*Environment Protection (Noise) Policy, 2007*), where day time periods are between 7am and 10pm (15 hours); while night time periods are between 10pm and 7am (9 hours).

Many environmental noise computational procedures incorporate the assumption that overall SPLs are distributed normally. The large volume of urban noise data collected during long term monitoring provides good groundwork for exploring this assumption. Similar to the procedure above, the SPLs measured over 15 min intervals such as

L_{eq} , L_{Aeq} , and L_{Ceq} were standardized to arithmetic average SPL for each monitoring location and standard deviation:

$$Z_{15min} = (L_{j,15min} - \bar{L}_{j,15min}) / \sigma_{j,15min} \quad (2)$$

where $L_{j,15min}$ is the individual 15 minute SPL data point for j -th monitoring location, $\bar{L}_{j,15min}$ is the overall arithmetic average for j -th monitoring location and σ_j is the standard deviation computed for j -th monitoring location.

Formula (2) converts all the data points into their respective Z-scores which enables consequent statistical analysis of the combined data set. This normalisation method would allow for the distribution of the data from each monitoring location to be analysed together within the same scale (units of standard deviation). These standardized data points were separated into 20 bins corresponding to the respective means and standard deviations for each monitoring location and utilised for further post-processing.

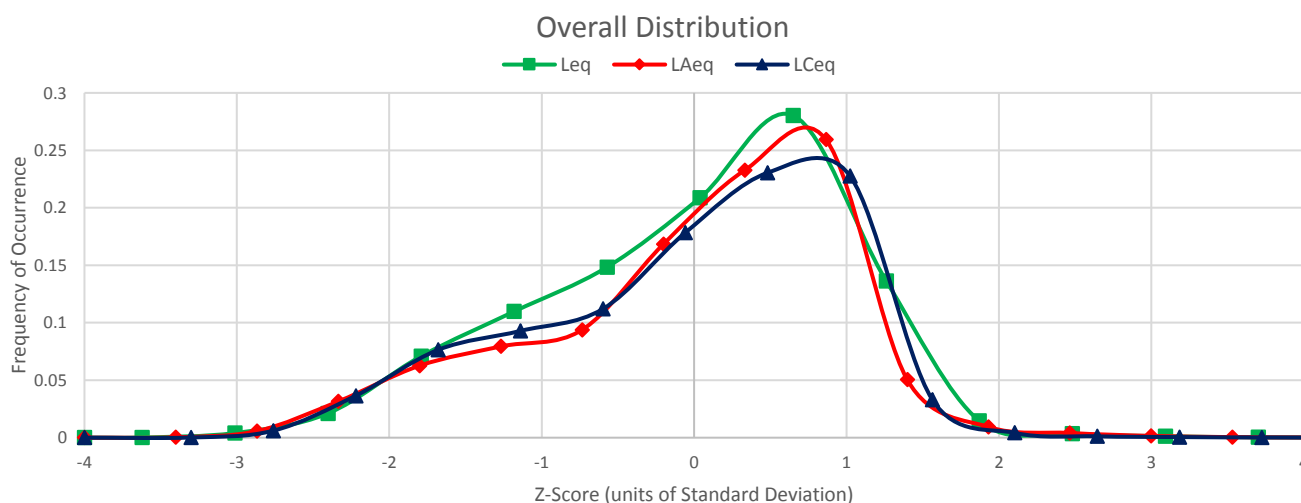


Figure 2: Distribution of Z-score for Unweighted, A-weighted and C-weighted SPLs, over 24 hour data

Figure 2 shows the distribution of the overall SPLs over the 12 month monitoring period. A total of 202,279 valid data points were used for the frequency of occurrence calculations. Figure 2 shows that the overall distribution throughout the 12 month monitoring period was not normal and was left skewed, where the mode of the distribution is between a half and one unit of standard deviation. This was likely caused by longer day time hours that are generally characterised by higher SPLs.

Figure 3 (a) and (b) show the distribution when day and night time periods are analysed separately. As can be seen from these figures, day time noise levels show a left skew similar to the overall 24 hour distribution. Night time distribution for L_{Aeq} is perceptively closer to the shape of a theoretical normal distribution, while L_{eq} and L_{Ceq} had a slight right skew to the data. It is not necessary to perform statistical tests on the 24 hour or day time distributions to confirm that these distributions were not normal. However, the night time distribution looks perceptively close enough to the theoretical normal distribution that can be verified by a relevant statistical test. Several normality tests were undertaken on the full sample size such as: Chi square goodness of fit test and Kolmogorov-Smirnov test. These normality tests returned a negative result, indicating that the distribution is still not normal at acceptable levels of significance (alpha of 0.05).

It is possible that these normality tests return negative results due to the large number of samples used during these tests. Alternatively, splitting up the samples, or analysing the data over shorter time periods (for example monthly instead of yearly) might bring positive results for the normality tests.

3 SPECTRAL COMPONENTS AND CORRELATIONS OF URBAN NOISE

3.1 Generic spectrum of urban noise

The apparent similarity of time histories and spectral content for all monitoring locations in the CBD allows for exploration of the concept of a generic spectrum which would be similar for the entire area from a statistical perspective. This generic spectrum can be utilised for modelling and noise prediction purposes for an urban area in order to facilitate effective urban planning solutions.

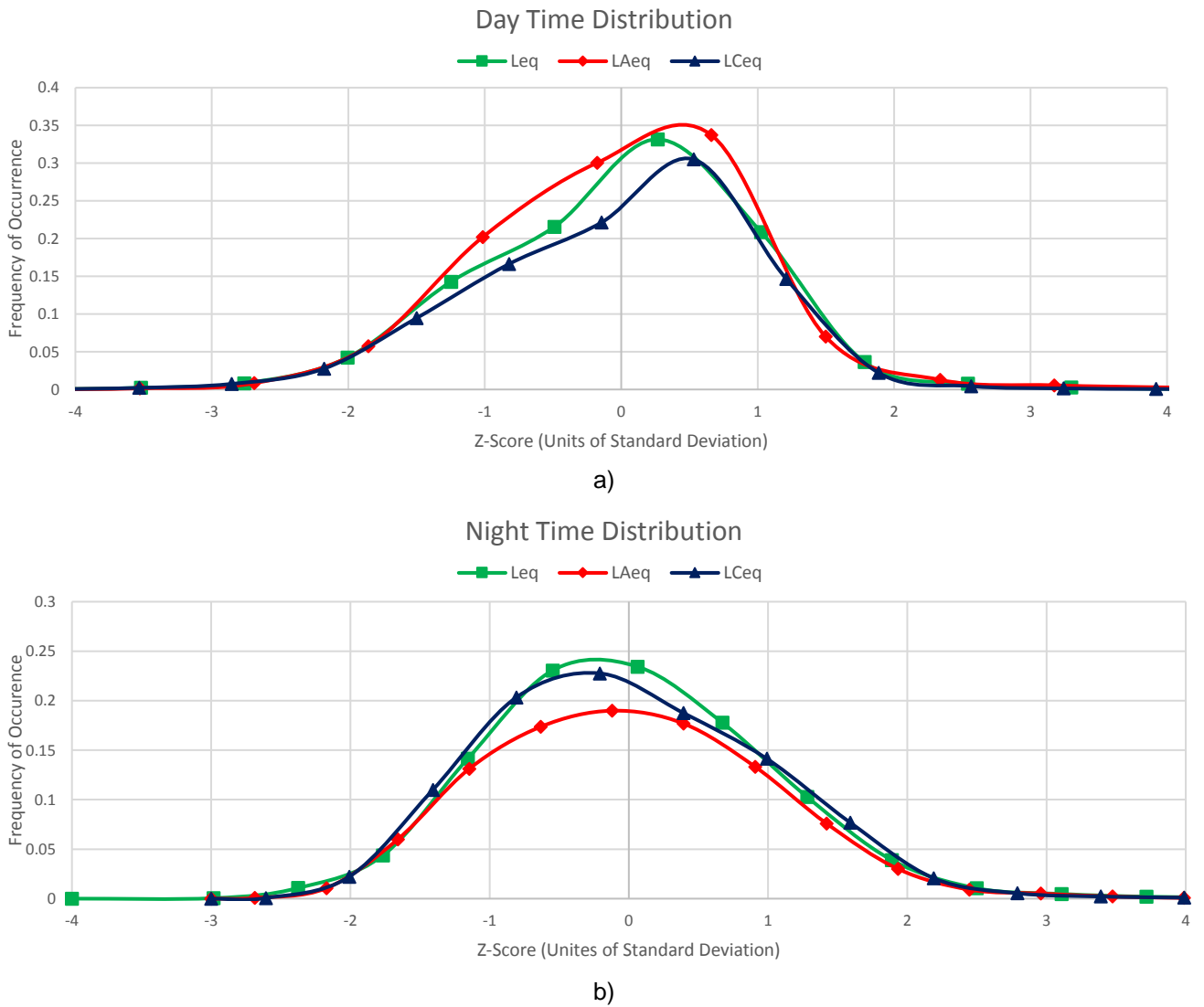
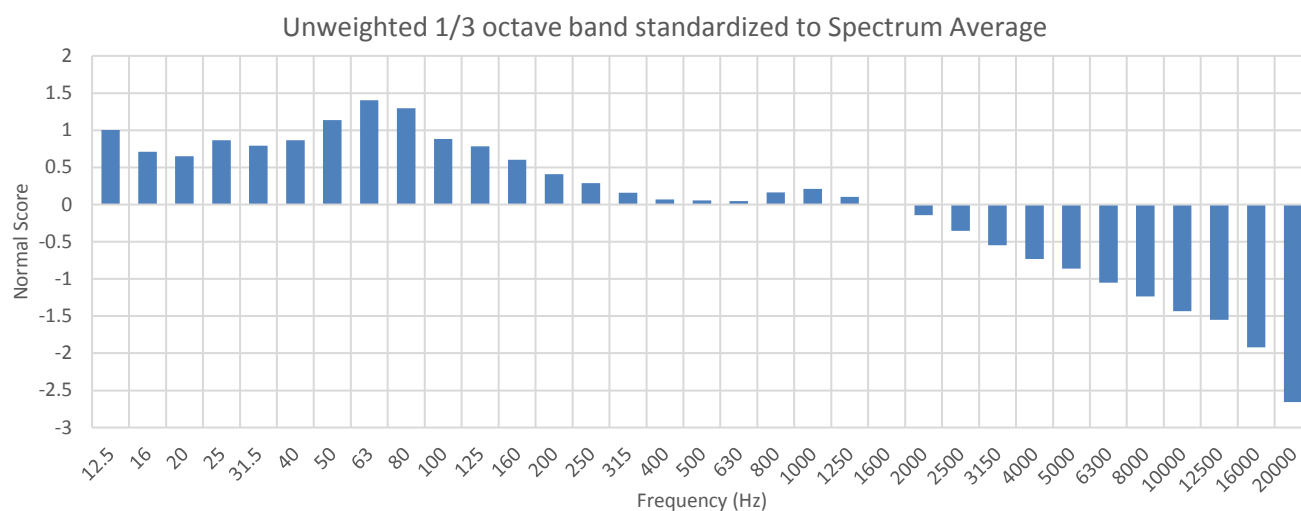
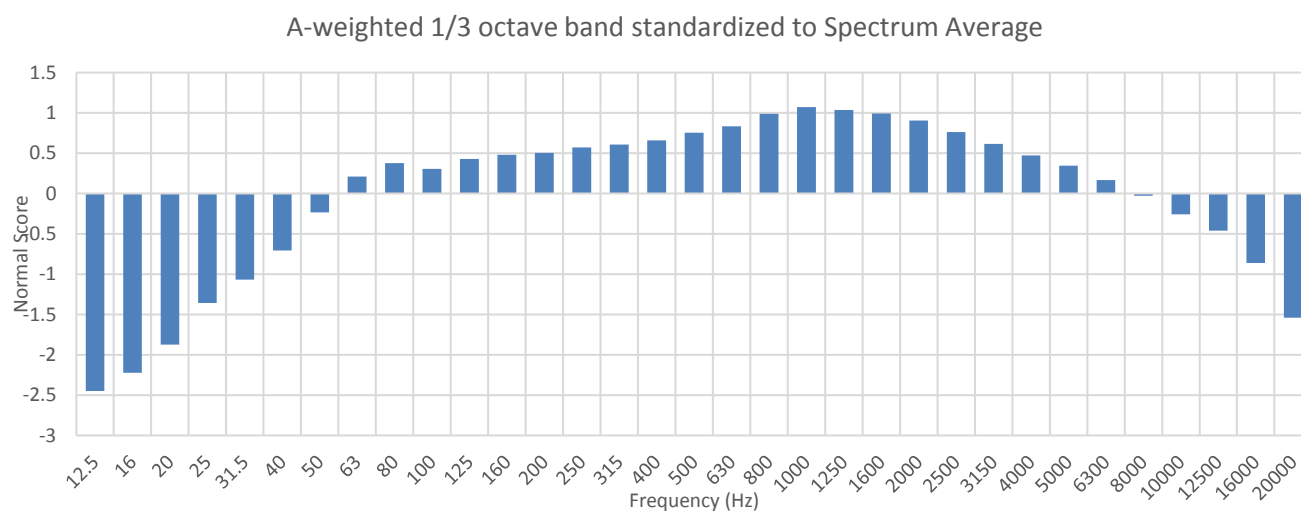


Figure 3: Distribution of Z-Scores for Unweighted, A-weighted and C-weighted SPLs: a) day time, b) night time



(a)



(b)

Figure 4: Generic (a) unweighted and (b) A-weighted noise spectrum for Adelaide CBD normalized to the spectrum average and standard deviation

Figure 4 (a) and (b) show the unweighted and A-weighted spectrum when standardized to the overall spectrum average respectively. Figure (a) shows that the frequency content in the urban environment was relatively broadband with the highest magnitudes at 63Hz and adjacent frequency bands. It is highly likely that these peaks can be associated with the contribution of traffic noise, which is particularly prominent at urban locations. These frequencies may also be affected by sources such as entertainment music noise, which was detected at 2 of the monitoring locations. There is also a local maximum at 1kHz 1/3 octave central frequency. This is further emphasised in Figure (b) showing that the 1kHz and adjacent frequency band had the highest magnitudes when considering the spectrum after A-weighting was applied.

The figure shows that the highest contributions to the overall unweighted SPL is brought by spectral components between 50Hz and 80Hz, while 1kHz generally dictates the A-weighted spectrum. The following section (3.2) explores the correlations between these frequency bands and the overall SPLs considered within this paper. These normalized levels can also facilitate design and planning solutions for urban noise mitigation in environments with significant traffic contribution. This may indicate that noise between 50Hz and 80 Hz and between 800Hz and 1.25kHz should be considered with high priority when designing noise mitigation in an urban environment.

3.2 Correlation between frequency components and SPLs

Processing of data records for analysis of spectral components shows a high degree of correlation between magnitudes in their neighbourhood 1/3 octave bands and generally high correlation between 1/3 octave components within the same octave. Typically 1/3 octave magnitudes within the same octave are correlated with Pearson's

correlation coefficient exceeding 0.8. This can be considered as an indication of frequency resolution requirements for urban noise predictions and reporting. Noise calculations and measurements performed for octave bands is seemingly sufficient for general environmental noise assessment if simplified tonality assessment based on 1/3 octave magnitudes is not required.

Tables containing large amounts of correlation coefficients were omitted from this paper and represented as surface plots for ease of processing and reading. Figure 5 shows a surface chart for correlations of one third octave a) and octave band central frequencies b). When compared, these charts show high similarity indicating that octave band values may be sufficient for general environmental noise assessment. Figure 5 a) with 1/3 octave data shows more clearly that there are areas of high (correlation coefficient above 0.8) and low correlation. It is possible to group these one third octave estimates into groups depending on the degree of correlation: Very Low, Low, Low Middle, High Middle, High and Very High Frequencies.

Table 1 summarises these groups based on the correlation coefficient which can also be seen in Figure 5a). These categories group the 1/3 octave frequencies that have a correlation coefficient of 0.8 or more with its neighbouring 1/3 octave frequencies based on Figure 5a). Several solid lines in Figure 5a) indicate the groupings that are described within Table 1. The very low and very high frequency SPL estimates generally do not correlate with other groups apart from themselves. As can be seen in Figure 5a), it is difficult to derive boundaries for the middle frequencies since they do not have clear lines of separation, and generally also have a good correlation coefficient with the neighbouring frequencies. Therefore, some of the boundaries suggested in the Table 1 cannot be clearly defined and can only be used as a guideline.

Table 1: Classification of 1/3 octave frequencies based on the correlation coefficient

Classification	Central 1/3 Octave Frequencies
Very Low	12.5Hz – 20Hz
Low	25Hz – 80Hz
Low Middle	100Hz – 500Hz
High Middle	630Hz – 5kHz
High	6.3kHz – 12.5kHz
Very High	16kHz – 20kHz

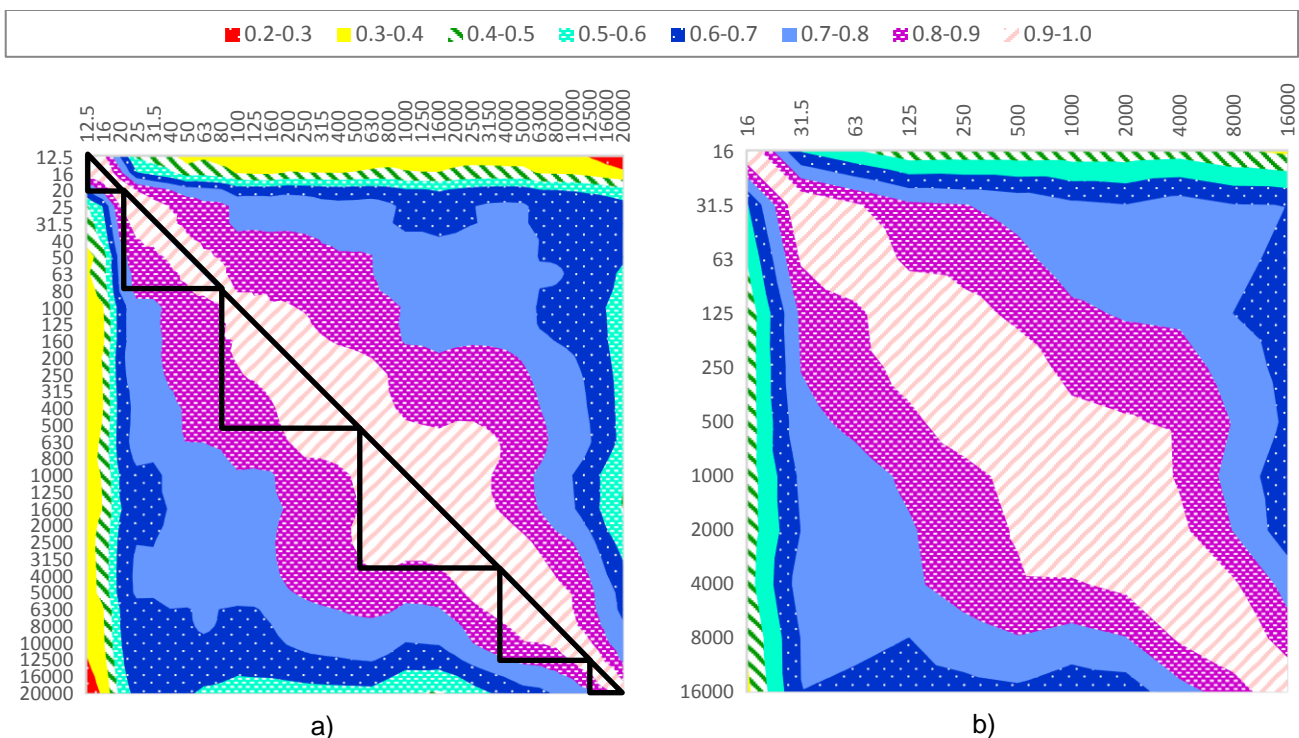


Figure 5: Correlation chart between central frequency for (a) one third octave and (b) octave band

After considering the correlations between the frequency components, it would also be beneficial to explore the correlations between overall SPLs and the octave spectral components. Table 2 details Pearson correlation coefficient estimates between overall magnitudes and levels in particular octaves. Practically all of the spectral values were well correlated with unweighted SPLs. As it may be expected, A-weighted magnitudes had highest correlation with 1000Hz and adjacent spectral components. Application of C-weighting increased estimates of the correlation coefficient for the low frequencies in comparison with A-weighted SPLs. The greatest correlation for C-weighted levels is shifted to 63Hz and adjacent octave frequency bands. It corresponds to the spectral peak in the generic unweighted spectrum computed for the monitoring area. Table 3 shows the Pearson correlation coefficient among the overall SPLs. Due to the broadband nature of noise in urban situations, the high correlation between the overall SPLs shown in the table were expected.

Table 2: Average correlation coefficient between overall SPLs and octave spectral components

	16	31.5	63	125	250	500	1000	2000	4000	8000	16000
Leq	0.69	0.93	0.94	0.87	0.87	0.84	0.79	0.77	0.80	0.73	0.68
LAeq	0.46	0.77	0.82	0.86	0.92	0.96	0.99	0.98	0.93	0.82	0.69
LCeq	0.55	0.92	0.98	0.93	0.92	0.88	0.83	0.81	0.83	0.76	0.70

Table 3: Correlation coefficient between overall SPLs

	L_{eq}	L_{Aeq}	L_{Ceq}
L_{eq}	1	0.84	0.98
L_{Aeq}	0.84	1	0.88
L_{Ceq}	0.98	0.88	1

4 SUMMARY

Statistical analysis of a large amount of data collected in the urban environment shows the similarity between noise variation patterns measured at different monitoring locations. This allows for computations of a generic daily time history graph.

The probability distribution graphs show that noise in urban environments is generally not normally distributed. Although night time noise distributions resembled that of a normal distribution, statistical normality tests have shown that they were not normal.

It is shown that A-weighted, C-weighted and unweighted SPLs demonstrate significant correlation. Therefore, based on this set of data acquired, additional specification for environmental noise limits may not be necessary. Environmental noise limits based on A-weighted levels can be considered sufficient unless more in depth analysis for individual noise sources is required. Similar conclusions can be drawn in respect to the typical frequency spectrums measured in the CBD. High correlation of 1/3 octave sound pressure levels within a relevant 1/1 octave indicated sufficiency of environmental noise measurements and reporting for just octave bands except in the cases where frequency analysis with a higher resolution may be required by other rationales. High correlation between SPLs in different frequency groups can be utilised for more accurate definitions of low, mid- and high frequency spans.

A generic frequency spectrum can be derived for the monitored area to be utilised for noise modelling and prediction purposes if it is difficult to perform an actual noise monitoring at some urban locations. Generic SPL time histories and frequency spectrums can be used to facilitate planning and noise management solutions in complex urban environments.

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