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Noise Levels Associated with Urban Land Use

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ABSTRACT *Recent trends towards the intensification of urban development to increase urban densities and avoid sprawl should be accompanied by research into the potential for related health impacts from environmental exposure. The objective of the current study was to examine the effect of the built environment and land use on levels of environmental noise. Two different study areas were selected using a combination of small area census geography, land use information, air photography, and ground-truthing. The first study area represented residential land use and consisted of two- to three-story single-family homes. The second study area was characteristic of mixed-use urban planning with apartment buildings as well as commercial and institutional development. Study areas were subdivided into six grids, and a location was randomly selected within each grid for noise monitoring. Each location was sampled four times over a 24-h day, resulting in a total of 24 samples for each of the two areas. Results showed significant variability in noise within study areas and significantly higher levels of environmental noise in the mixed-use area. Both study areas exceeded recommended noise limits when evaluated against World Health Organization guidelines and yielded average noise events values in the moderate to serious annoyance range with the potential to obscure normal conversation and cause sleep disturbance.*

KEYWORDS *Noise, Land use, Urban, Geographic information systems, Sound level meter*

INTRODUCTION

The human environment has become increasingly shaped by urbanization and the built environment, which comprises the physical infrastructure arising from urban development as well as managed green space such as urban forests, parks, and sport fields.[1] Indeed, more than half of the global population and over 80 % of North Americans now reside in urban areas.[2] The built environment is now attracting the attention of public and environmental health researchers, as its inherent quality, characteristics, and spatial orientation (i.e., urban sprawl) have been linked both positively (e.g., parks, trails) and negatively (obesity, injuries, stress) to a variety of health outcomes.[3,4] Increasing urbanization has been linked to a rise in the prevalence of health disparities, as well as a growing culture of sedentary living,

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contributing to the development of several chronic disease outcomes.[5] In efforts to improve urban conditions and enhance human well-being, municipal planning groups have developed and promoted several initiatives, including mixed-use development strategies. A potential consequence of these strategies is an increase in environmental noise levels.

Environmental noise is an increasingly common feature of urban areas that can be described as an unwanted or undesirable sound within non-occupational settings. Road, rail, and air traffic sources account for the majority of noise in urban and surrounding areas.[6] Additional sources of noise include industrial/commercial enterprise, construction projects, and such familiar domestic sources as pets and radios/stereos. Municipal planning strategies emphasizing increases in urban development densities, mixed-uses, as well as a continuation of automobile-centered traffic planning policies may lead to an increase in population level exposure to traffic and related urban environmental noise. At present, little is known regarding how noise levels may vary with forms of urban development and affect the health of a population.

Environmental noise has been linked to several non-auditory, biologically relevant health outcomes, including: increased levels of hypertension and high blood pressure,[7] lowered cognitive ability,[8] and an increased prevalence of cardiovascular disease.[9] Exposure to environmental noise from traffic-related sources is reportedly the most annoying of all urban pollution types,[10] interfering with enjoyment of daily activities and largely affecting sleep and rest patterns.[10–12] In a recent Canadian survey, 20–28 % of urban populations attributed noise from road traffic to disruptions during sleep, conversation, and communication tasks such as reading and writing.[13] Few studies have conducted field measurements to assess levels of environmental noise in Canadian cities; furthermore, it is still unknown whether recent trends towards the intensification of urban development will impact environmental noise levels and in turn population health.

Acceptable noise level guidelines have been developed by several agencies based on levels of annoyance, interference with communications, disturbance to sleep, and the potential to cause hearing impairments.[14,15] For example the US Environmental Protection Agency recommended a maximum indoor noise level of 45 dB(A)* and outdoor noise level of 55 dB to allow for intelligible communication.[16] Typically, values are derived for specific settings and time periods. Some agencies also provide guidelines according to land use and population density (e.g., Italian legislation in 1997). Recommended urban residential noise levels generally range from 45 to 55 dB depending on the time of day and location of measurement. For example, Australian Environmental Protection Authority noise guidelines state that noise levels in urban residential neighborhoods should not exceed 55 dB(A) during the day and 47 dB(A) at night (i.e., from 22:00 to 06:00). The maximum recommended noise levels generally increase in relation to the amount of commercial activity, which presents challenges for cities developing policies related to integrated residential and commercial land uses.

As with many urban centers in Canada and abroad, the Halifax Regional Municipality intends to intensify urban development by combining residential and

*Sound is measured by comparing the logarithm of a given sound to a reference sound pressure, and is expressed on a logarithmic decibel (dB) scale. The A-weighting [dB (A)] system was devised to adjust results in studies examining the impact of environmental noise on human hearing specifically.

commercial land-use types. The objective is to promote mixed-use neighborhoods with focused development in core areas. A number of reasons have been cited for this development strategy including the high costs of municipal services and rising costs of health care (e.g., obesity, transportation injuries) related to sprawl and associated increased automobile use.[17–19] Research into these issues is required not only to protect the health and well-being of urban inhabitants, but also to ensure that planning decisions are based on evidence that considers the potential health and environmental consequences of development. To date, few studies have examined how noise varies as a function of urban development.

The aim of this study was to assess and compare noise levels in two urban neighborhoods: one completely residential and comprised of mostly single and multi-family dwellings, and the other characteristic of mixed residential and commercial land uses. Ambient environmental noise was recorded, measured, and analyzed within defined spatial locales in order to determine the potential for cumulative exposure to the local population. This research is timely and potentially informative given current trends in urban development.

METHODS

For the purpose of this study, two neighborhoods were selected: one almost exclusively residential to represent traditional planning strategies and the other comprised of residential and commercial land uses to represent more modern planning strategies that emphasize mixed-use development in urban core areas. The boundaries of each neighborhood matched the smallest statistical boundaries developed for the dissemination of Canadian census data (see Figure 1). Area 1, the representative residential area, mostly contained single-family dwelling units up to 10 m in height with 653 residents and a population density of approximately 3,950 persons per square kilometer. Buildings in this area are generally free standing and constructed of wood, stone, and brick. Area 1 also included seven roads (total length = 3,506 m) that either border or are situated within the area. Area 2, representing mixed commercial and residential land uses, was larger in area yet housed a smaller population of 566 residents (1,836.5 persons per square kilometer). This area is bounded by several major roads and is generally oriented east to west. Area 2 contains commercial, institutional, and residential zones, with mostly concrete multi-story buildings. Sixteen roads traversed the area totaling 6,271 m in length.

Sampling Strategy

Study areas 1 and 2 were each divided by a grid into six identical cells. A geographic information system was used to randomly select one sample site location within each cell in the following manner. First, road network polygons were imported and a 4-m buffer polygon was inserted from the edge of the road. Second, a spatial random point generator, constrained to one point per grid cell within the buffer polygon, identified six sampling locations per study area. As a result, one randomly selected sample point per grid square was included in the analysis (Figure 1). Forty-five-minute noise recordings were randomly sampled during each of four distinct time periods from each of the six sampling locations per study area.

Environmental noise sampling methods vary considerably. For example, studies have used a sampling frequency of 15-min measurements every 2 h,[20] while others have employed continuous assessments.[21] Studies have measured noise levels during

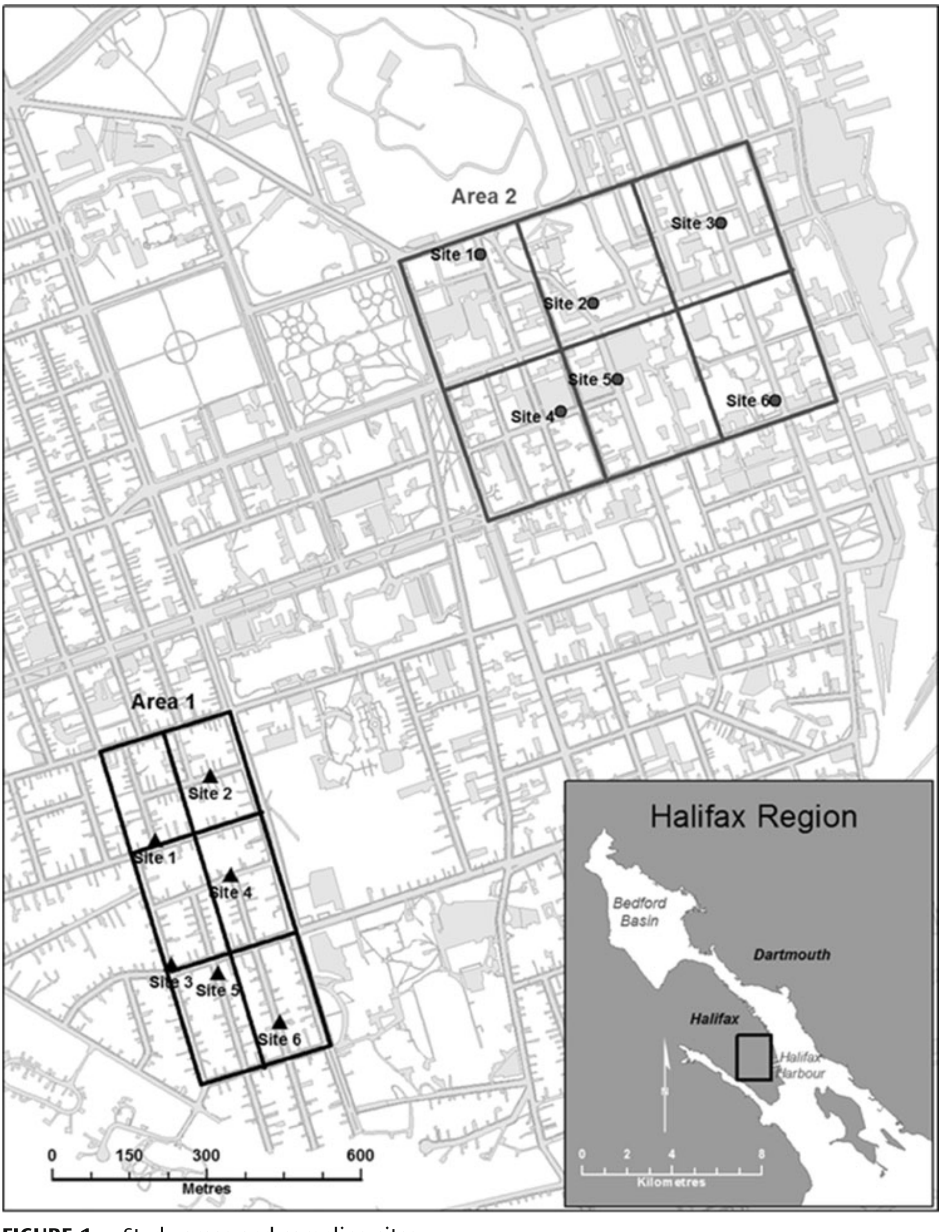

FIGURE 1. Study areas and sampling sites.

the day and at night,[22] while others have only considered measurements during the day.[23] In 2007, Ng and Tang adopted a three-period assessment in which a 24-h clock was divided into three periods (day, evening, and night) that differed slightly in their period start times and sample lengths.[24] For the purpose of the current study, we incorporated a modified version of the three-period assessment method with certain refinements, as discussed by Ng and Tang,[24] for improving statistical accuracy. Each sample location yielded 3 h of data distributed across four time periods (i.e., 45 min per sampling period for each location). Daytime periods were subdivided into morning (06:00–12:00 h) and afternoon (12:00–18:00 h) segments to enhance assessment quality. In addition, hours in the evening period (18:00–24:00 h) and the night period (24:00–06:00 h) were randomly sampled in order to capture the full daily spectrum of environmental noise production.

Data Collection

Noise data were collected using a Centre 322 Logging Sound Level Meter (SLM) and a Marantz PMD-660 Solid State Digital Recorder. The Centre SLM is an ANSI S1.4 Type 2 instrument with a 0.5″ electrets condenser microphone, frequency range of 31.5 Hz to 8 KHz, measuring level range of 30–130 dB, and capacity to weight frequencies to either the A or C scale. The Marantz PMD-660 Solid State Digital Recorder was connected to an external microphone that can record 4 h of data at frequencies of 44.1/48 KHz.

The SLM and sound recorder were mounted on a camera tripod and microphone stand at a height of 1.5 m, a distance of 0.5 m from the curb, and were oriented perpendicularly to the nearest road. The SLM logged noise using an average of 1 s measurements, while the digital sound recorder facilitated continuous recordings to qualitatively identify peak noise events. Recordings commenced at the top of each hour (e.g., 1:00, 2:00…); in addition, the particular time at which recordings commenced was randomly assigned to sample locations thereby ensuring that the full 6-h time period (i.e., day, afternoon, evening, and night) was sampled. No data collection occurred on days ($n=2$) with rain, snow, or high winds, because these elements can both damage equipment and decrease the accuracy of measurements. Preliminary analysis of noise data from a related and, as of yet, unpublished study found that weather conditions, precipitation and wind in particular, had no influence on noise levels measured at a frequency of one measurement per hour. This conclusion was derived from comparing statistically noise levels measured during high wind or rain events (or both) with noise levels during times when weatherproofing of instrumentation would not be required.

Data Analysis

The SLM data included the minimum and maximum sound pressure level (SPL) averaged over 1 s, which resulted in 2,700 data points for each sampled time period and 10,800 data points for each grid sample area in a 24-h period. Basic noise descriptors were calculated. In addition, the equivalent continuous sound pressure level ($L_{A\mathrm{eq}}$) and day–evening–night composite whole-day rating level (L_{Rden}) were derived for the sample periods, grid sample areas, and study areas to identify variations in environmental noise over both space and time.

The two study areas were statistically evaluated and compared. First, each study area was examined individually to determine the spatial variation of environmental noise during each 6-h period and the full 24-h period. Noise levels associated with individual sample sites within each study area were compared statistically using a series of Kruskal–Wallis tests for non-parametric data. Then, the two primary study areas were compared statistically using the Mann–Whitney two-sample rank test.

$L_{A\mathrm{eq}}$ values were compared with environmental noise exposure limits as dictated by Italian legislation (see Piccolo et al. 2005 for the exposure limits). In order to accomplish this, the study data were recalculated to correspond with the standardized time periods adopted by Italian legislation. This approach provided a means to determine levels of noise exposure with comparison to standards developed to prevent potential human health risk.

Calculation

Each study area yielded 18 h of data comprising 3 h per site (four time period samples of 45 min each). The A weighted equivalent continuous sound pressure level (L_{Aeq}) was calculated for each sample using the following formula:

$$L_{\mathrm{Aeq}} = \frac{10\left(\log \frac{1}{T}\right) \int P_A{}^2(t)}{p_o{}^2(dt)} \tag{1}$$

$P_A{}^2$ – The A-weighted instantaneous sound pressure at the running time t;
p_o – The standard reference sound 20 μPa

The resultant L_{Aeq} values were then adjusted according to the particular sampled time period (+5 dB for evening hours and +10 dB for night-time hours) using the formula indicated below:

$$L_{\mathrm{Req}j,Tn} = L_{\mathrm{Aeq}j,Tn} + K_j \tag{2}$$

K_j – Adjustment for the specified sample and time period;
$L_{Aeqj,Tn}$ – The actual L_{Aeq} value at the specified time period

Using the adjusted L_{Aeq} values, the day–evening–night rating levels were derived using the following formula:

$$L_{Rden} = 10\log\left[\frac{d}{24} \times 10^{\frac{LRd}{10}} + \frac{e}{24} \times 10^{\frac{LRe}{10}} + \frac{(24-d-e)}{24} \times 10^{\frac{LRn}{10}}\right] db \tag{3}$$

d – The number of daytime hours;
n – The number of night-time hours;
e – The number of evening hours;
L_{Rd} – The rating level for daytime hours including adjustments;
L_{Re} – The rating level for evening hours including adjustments;
L_{Rn} – The rating level for night-time hours including adjustments

RESULTS

Area 1

The distribution of sound in area 1 was skewed to the right and somewhat peaked with an overall mean sound level of 48.1 dB(A) (SD = 7.6) and substantial variation among individual sites (Table 1). Maximum values for the individual sites ranged from 60.6 dB(A) at site 6 to 93.3 dB(A) at site 3, while minimum values ranged from 20.0 dB(A) at site 3 to 47.0 dB(A) at site 4. Site 3 evidenced the greatest range of sound with night recordings of 20.0 dB(A) to 93.3 dB(A). L_{A90} values (90th percentile), representing background noise in the area, ranged from a low of 38.2 dB (A) at site 3 to a high of 50.3 dB(A) at site 4. Site 3 yielded higher than average L_{A1} values (1st percentile), indicating high levels of road traffic near the sample points. Adjusted (Adj) L_{Aeq} values ranged from a low of 44.7 dB(A) at site 6 to a high of 76.8 dB(A) at site 3. A comparison of the four sample time periods across sites evidenced maximum SPLs between 71.3 dB(A) and 77.4 dB(A) and mean SPLs from a low of 44.0 dB(A) to a high of 51.5 dB(A) (Table 2). L_{A90} values for the four time periods ranged from a low of 41.6 dB(A) to a high of 45.4 dB(A), while Adj L_{Aeq} ($\bar{x} = 57.3$ dB(A)) values ranged from a low of 56.0 dB(A) to a high of 59.1 dB(A). Table 1 shows site 3 ($\bar{x} = 68.9$ dB(A)) and the night period ($\bar{x} = 59.1$ dB(A)) as having the highest overall Adj L_{Aeq} levels.

TABLE 1 Summary statistics for area 1

Site	Period	Start time	Max	Min	Mean	Percentiles L_{A1}	Percentiles L_{A90}	L_{Aeq}	Adj L_{Aeq}
1	1	07:00	73.0	40.1	44.2	60.0	41.8	48.5	48.5
	2	16:00	73.3	41.4	47.7	65.1	42.8	53.2	53.2
	3	18:00	66.6	25.8	43.9	61.8	39.5	49.2	54.2
	4	03:00	66.3	41.7	43.9	51.6	42.8	45.0	55.0
2	1	08:00	72.9	43.7	51.3	67.4	46.3	55.4	55.4
	2	12:00	75.4	40.9	48.0	63.7	43.3	53.0	53.0
	3	22:00	65.2	21	44.2	55.9	41.5	46.6	51.6
	4	01:00	66.3	38.8	40.3	49.2	39.4	42.0	52.0
3	1	09:00	90.0	42.3	61.4	80.3	48.0	69.1	69.1
	2	14:00	86.6	40.0	57.7	76.3	45.7	66.3	66.3
	3	23:00	81.4	37.0	43.1	72.1	38.2	58.6	63.6
	4	05:00	93.3	20.0	48.0	77.6	43.3	66.8	76.8
4	1	10:00	79.8	47.0	58.1	67.1	50.3	63.1	63.1
	2	15:00	77.5	23.0	49.0	56.7	43.0	54.8	54.8
	3	21:00	78.9	43.9	53.8	63.7	46.8	60.0	65.0
	4	24:00	77.4	39.9	45.8	55.0	41.3	52.9	62.9
5	1	11:00	72.7	41.6	50.8	66.6	43.9	55.4	55.4
	2	13:00	77.5	23.0	49.0	66.7	43.0	54.8	54.8
	3	19:00	73.9	37.8	48.4	65.0	40.5	54.2	59.2
	4	04:00	63.7	42.2	44.4	53.4	43.0	45.2	55.2
6	1	06:00	67.9	40.5	43.1	50.0	41.9	44.7	44.7
	2	17:00	73.8	42.6	49.8	66.5	45.6	54.6	54.6
	3	20:00	73.4	41.2	45.5	61.7	43.0	50.3	55.3
	4	02:00	60.6	38.3	41.7	51.5	40.2	42.7	52.7

As evident from Table 1, Adj L_{Aeq} values peaked at 05:00, 09:00, 14:00, and 23:00 (site 3), as well as at 21:00 and 00:00 (site 4). L_{Aeq} values mirrored this trend. The results suggest that the maximum values associated with these particular sites may have augmented the average noise level of the study area. The composite whole day rating for area 1 equaled 63.8 dB(A).

A significant difference in noise among individual sample sites in area 1 was observed, χ^2 $(5, N=24)=16.2$, $p=0.01$. Site 6 was associated with the lowest Adj L_{Aeq} levels in the area ($\bar{x} = 51.8$) yet produced a comparatively high number of outlier values throughout the day from elevated noise events. Site 3, which contributed the highest levels of environmental noise in area 1 ($\bar{x} = 68.9$), yielded a different data distribution pattern with fewer outlier points all of which occurred in the evening and night-time periods. A similar comparison across time periods failed to yield a significant difference, χ^2 $(3, N=24)=0.55$, $p=0.91$.

TABLE 2 Statistical values for area 1 by sample time period

	Max	Mean	L_{A1}	L_{A90}	L_{Aeq}	Adj L_{Aeq}
Morning	76.0	51.5	66.4	45.4	56.0	56.0
Afternoon	77.4	50.2	67.5	43.9	56.1	56.1
Evening	73.2	46.5	64.6	41.6	53.2	58.2
Night	71.3	44.0	57.8	41.7	49.1	59.1

Area 2

Data from area 2 yielded a similar distribution to area 1 with an overall mean of 56.6 dB(A). However, area 2 evidenced less variation in recorded sound values among individual sites and time periods (Table 3). Peak SPLs ranged from 69.7 dB (A) at site 2 to 90.3 dB(A) at site 6, while L_{A90} values ranged from a low of 44.0 dB (A) at site 6 to a high of 59.3 dB(A) at site 1. Adj L_{Aeq} values across sites ranged from a low of 55.4 dB(A) at site 4 to a high of 72.2 dB(A) at site 6. A comparison of the four sample time periods across sites yielded maximum SPLs between 77.2 dB(A) and 84.9 dB(A). L_{A90} values for the four time periods ranged from a low of 47.1 dB (A) to a high of 54.6 dB(A), while Adj L_{Aeq} values ranged from 61.8 dB(A) in the afternoon to 66.3 dB(A) at night (Table 4). The results indicate that area 2, the mixed use area, is associated with a more consistent level of environmental noise across sample sites. For example, L_{A90} values were highest recording in the afternoon at 54.6 dB(A), which varied little from the morning value of 53.1 dB (A), and then decreased through the evening to 47.1 dB(A) at night. Site 6 ($\bar{x} = 69.9$ dB(A)) and the night period ($\bar{x} = 66.3$ dB(A)) were associated with the highest overall Adj L_{Aeq} values (Table 3).

Table 3 displays L_{Aeq} and Adj L_{Aeq} values for selected sites over a 24-h period. As evident from this table, area 2 yielded Adj L_{Aeq} peaks at 01:00 (site 5), 03:00, 07:00,

TABLE 3 Summary statistics for area 2

						Percentiles			
Site	Period	Start time	Max	Min	Mean	L_{A1}	L_{A90}	L_{Aeq}	Adj L_{Aeq}
1	1	09:00	87.0	52.3	63.1	79.1	56.4	68.2	68.2
	2	12:00	88.3	55.4	65.1	75.9	59.3	68.1	68.1
	3	20:00	77.3	49.1	56.0	69.1	51.4	59.0	64.0
	4	02:00	79.4	42.3	50.0	65.3	45.9	55.8	65.8
2	1	08:00	89.0	46.7	58.3	75.1	52.2	65.0	65.0
	2	14:00	85.9	46.7	56.0	69.3	51.9	60.8	60.8
	3	23:00	77.8	48.9	53.4	67.3	50.2	56.7	61.7
	4	04:00	69.7	42.5	47.3	59.9	44.9	49.6	59.6
3	1	10:00	86.8	54.5	60.8	77.0	56.2	66.0	66.0
	2	15:00	85.2	54.3	60.3	71.6	56.6	62.7	62.7
	3	18:00	83.3	54.1	60.4	72.5	55.9	63.5	68.5
	4	05:00	75.1	49.7	54.0	67.5	51.5	56.4	66.4
4	1	11:00	72.7	45.4	52.6	65.9	49.0	55.4	55.4
	2	13:00	83.4	47.3	53.7	67.7	50.0	58.5	58.5
	3	22:00	75.1	28.6	50.4	66.0	47.2	54.1	59.1
	4	24:00	71.9	45.7	49.7	62.9	47.3	52.4	62.4
5	1	06:00	77.3	47.4	54.0	70.1	49.0	58.9	58.9
	2	16:00	86.0	23.7	60.9	72.1	55.0	64.0	64.0
	3	19:00	77.6	48.5	57.7	72.3	51.7	62.1	67.1
	4	01:00	85.7	46.2	53.8	73.5	49.1	61.3	71.3
6	1	07:00	90.3	49.8	65.6	81.3	56.0	71.1	71.1
	2	17:00	80.4	49.6	63.1	75.7	54.9	66.7	66.7
	3	21:00	83.7	46.7	60.1	74.3	51.8	64.8	69.8
	4	03:00	81.4	23.6	51.7	75.6	44.0	62.2	72.2

TABLE 4 Statistical values for area 2 by sample time period

	Max	Mean	L_{A1}	L_{A90}	L_{Aeq}	Adj L_{Aeq}
Morning	83.9	59.1	74.8	53.1	64.1	64.1
Afternoon	84.9	59.9	72.1	54.6	61.8	61.8
Evening	79.1	56.3	70.3	51.4	60.0	65.0
Night	77.2	51.1	67.5	47.1	56.3	66.3

and 21:00 (site 6). L_{Aeq} values, although deflated, mirrored this trend. The composite whole day rating was calculated and produced a result of 65.0 dB(A).

A significant difference in noise among individual sample sites in area 2 was yielded, χ^2 (5, N=24)=14.51, p=0.01. However, a similar comparison across time periods failed to yield a significant difference, χ^2 (3, N=24)=1.29, p=0.73. Areas 2 and 1 sample sites exhibited similar patterns of variation among sample sites and time periods; still, area 2 evidenced fewer outlier points due to higher overall levels of environmental noise. Traffic events characteristic of area 2 were absorbed by ambient background noise and therefore did not produce significant increases in sound. In contrast, sample sites associated with less road traffic and therefore lower ambient levels of noise produced more outlier points.

Comparison Between Areas 1 and 2

Differences were observed between the two sample areas both in terms of noise distribution and overall levels of environmental noise. First, Adj L_{Aeq} values among area 1 sites presented greater overall variability than area 2 sites (Figure 2). This difference can be attributed to variations in traffic volume related to land use, background institutional noise, and pedestrian activity. The noisier sites in area 1 were located near major roads, while sites associated with less noise were located further from the same roads. Although area 2 evidenced higher overall levels of environmental noise, sample sites produced fairly consistent and stable noise recordings. The consistency in noise levels across sites in area 2 likely relates to land use and background noise. More specifically, area 2 produces greater levels of background noise throughout the day from vehicle traffic in the area, industrial sounds (e.g., ventilation fans), delivery trucks, and high pedestrian traffic. This is confirmed by the higher L_{A90} values (representing background noise) in area 2 in addition to higher Adj L_{Aeq} values as a result of land use.

Results indicate that area 1 is more influenced by the disturbance effect of noise events. For example, a moving vehicle may generate an increase in sound levels of 10.0–30.0 dB(A), which would certainly lead to residential disturbances in area 1, yet remain unnoticed in the higher background sound levels inherent to area 2. It should be mentioned that the composite full day rating (L_{Rden}) values for the two areas evidenced very little difference in daily sound exposure (area 1=63.8 dB(A); area 2=65.0 dB(A)).

Findings from the Kruskal–Wallis tests provide evidence of statistically different levels of environmental noise among sample sites in areas 1 and 2. Using the Mann–Whitney test, a significant difference in Adj L_{Aeq} values associated with area 1 (mdn=55.1) and area 2 (mdn=65.4) was obtained (U=102, p=0.0001, r=0.56), thus supporting the hypothesis that land use (e.g., built environments) affects levels of environmental noise.

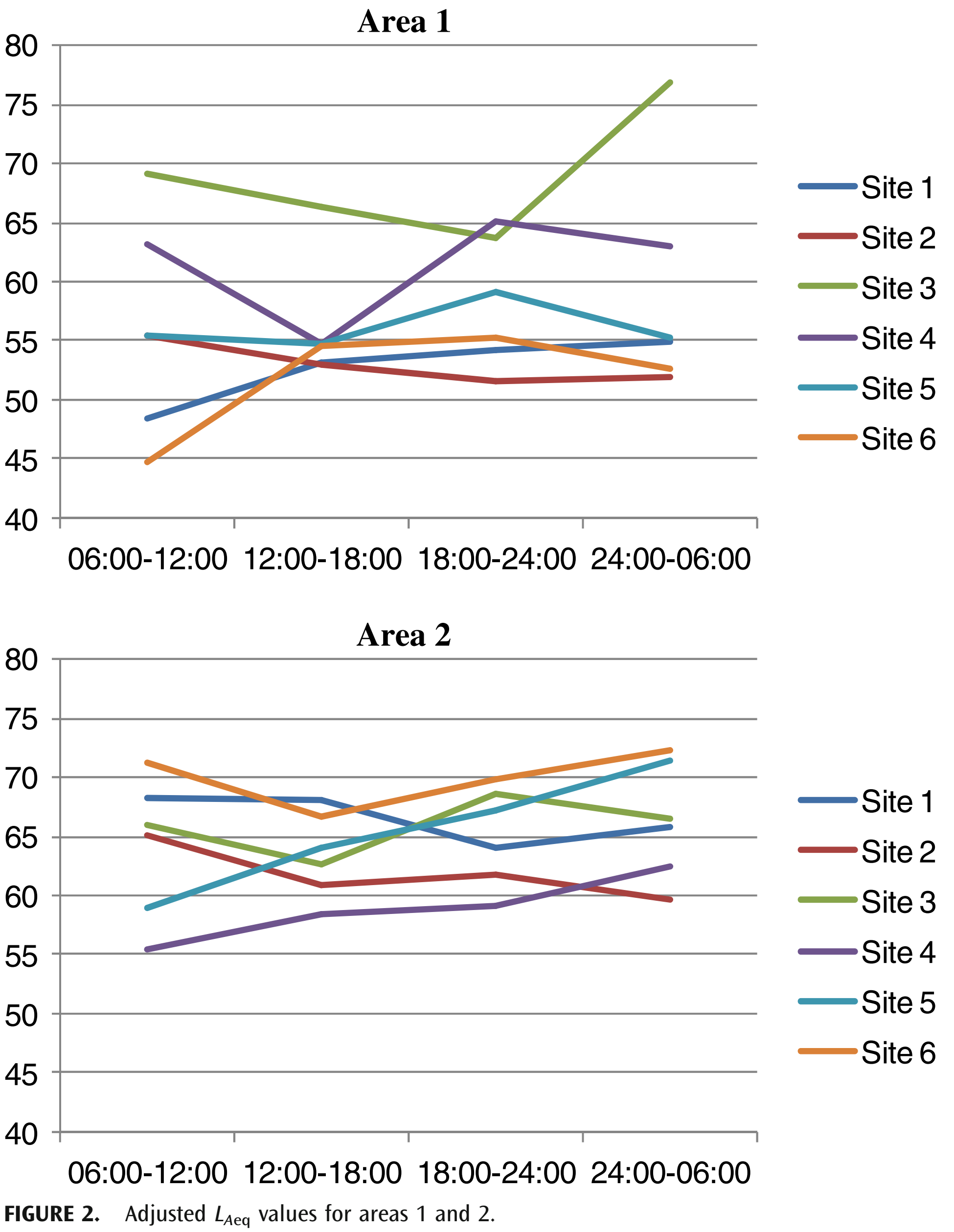

FIGURE 2. Adjusted L_{Aeq} values for areas 1 and 2.

DISCUSSION

The objective of the current research was to investigate and analyze spatial and temporal variations in environmental noise with respect to land use, specifically the built urban environment. In the analyses it was important to account for differences between neighborhood types in order to assess how increasing the frequency of mixed-used development land use would impact urban environmental noise levels. First, we found that noise levels varied significantly between residential and mixed-use neighborhoods. Noise levels in the mixed-use neighborhood were significantly greater than in the residential neighborhood. Second, noise values were analyzed to determine the spatial and temporal variability within and between sample sites. Greater variation in noise levels was found in the residential neighborhood. This reflected the co-location of the sound-level recording with major roads bounding the sample area, as well as specific traffic-related noise sources such as buses, trucks, and street cleaning equipment. Noise variation within the sample areas was much greater in the residential neighborhood.

Analyses revealed statistically significantly higher levels of environmental noise in the mixed-use neighborhood (area 2) compared to the predominantly residential neighborhood (area 1). Area 1 generated absolute environmental noise levels within the range of an office environment or normal conversation both of which are considered comfortable for human hearing. Area 2, on the other hand, produced higher absolute environmental noise levels considered, according to annoyance scales, intrusive and slightly annoying. Noise values were on average (L_{eq}) 8 db(A) greater during the day and 6 dB(A) greater during night-time hours in the mixed-use neighborhood. The higher overall levels of noise in area 2 likely reflect the continual presence of vehicular and pedestrian traffic in the area as well as background noise generated by institutional and industrial noise sources such as delivery trucks and ventilation systems. Evaluated against World Health Organization guidelines, both study areas yielded average noise events values in the moderate to serious annoyance range with the potential to obscure normal conversation and cause sleep disturbance.[14]

Our results also show significant variability in environmental noise *within* sample areas. With respect to area 1, environmental noise appeared to vary as a function of traffic patterns. For example, sites nearer to high traffic roads (e.g., heavy truck or bus traffic) presented higher levels of environmental noise. Because residential zones such as area 1 are associated with low(er) levels of background (i.e., continuous environmental noise) noise, traffic events can potentially contribute to high levels of disruption and disturbance. For example, people living close to site 3 in the residential area experienced on average a 10-dB(A) higher noise level during night-time hours compared to residents living elsewhere in the study area (Table 3). Site 3 is closest to two relatively major roads that are preferred routes for commuter, truck, and traffic from public transit (buses). In contrast, area 2 is associated with higher levels of background noise from steady traffic flow; consequently, results evidenced less intra-study area variability in noise despite the higher levels of noise associated with sites near high-traffic roads.

Our sampling approach also included measurement at random points within defined time periods to ensure sufficient noise measurements over a 24-h period. We did not find significant differences in average noise values across study sites within each sample area (Figure 2). Noise levels were somewhat higher during daytime hours, although the differences with evening and night-time measurements were minimized once values were adjusted. The consistency of noise values among day, evening, and night-time periods in urban environments has also been found in other studies.[20,25]

Although noise values in both study areas did not vary significantly over time, there was relatively good correspondence in the intensity of average adjusted values between areas for the time periods selected. For example, noise levels increased incrementally from the afternoon, through the evening, and peaked in the overnight hours for both study areas, even though there was an overall difference in absolute noise levels. In both areas, adjusted noise levels were greater in the overnight hours, particularly for the residential study area (area 1). Adjusted noise levels in the residential study area will be affected greatly by unusual noise sources, such as loud motorcycles, automobiles, or even bus traffic, since typical noise values are much lower throughout the day. Normally quiet neighborhoods in urban areas may thus be particularly prone to noise disturbances, especially during evening and night-time periods.

These findings support our initial hypothesis about the potential for variation in noise levels as a function of land use development in an urban environment. Urban planning initiatives developed to intensify urban development and promote mixed-use development may consider the potential for increased human exposure to noise and "design with noise in mind", especially as there is good evidence in support of an association between environmental noise and stress-related health effects.[7,9] When compared to guidelines designed to protect environmental quality and human health, adjusted noise levels in both areas exceed available recommended values for residential and mixed-use development and are indicative of relatively intensive land use development strategy (Table 5). Although Halifax is not a large city (population in 2006 of 372,675), noise levels in the mixed-use neighborhood are comparable to those measured in much larger urban centers such as Stockholm and Göteborg ($L_{Aeq,\ 24h}$=62 dB),[26] San Fransisco (L_{dn}=65 dB),[12] and Vancouver ($L_{Aeq,\ 5min}$=61.7 dB).[27]

From a public health perspective, noise levels measured in this study are of sufficient intensity to be injurious. For example, a 5-dB(A) increase in noise level between 45 and 65 dB(A) has been associated with a 38 % increased odds for hypertension even after control for several well-known risk factors.[28] The most deleterious health impacts arise from excessive noise exposures resulting in sleep disturbance. Sleep is a process of mental and physiological recovery essential to healthy functioning. It has been estimated that between 50 and 150 noise-induced awakenings per year may occur at outdoor noise levels equivalent to those measured in this study.[29] Subsequent impacts to health and well-being are numerous, including: impairment to cognitive performance, changes in hormone (epinephrine) levels, and changes in heart rate, sleep patterns, and mood. Ultimately, the constellation of noise-induced morbidities can lead to more severe health outcomes at noise levels not much greater than those measured in this study. Several studies have demonstrated an increased prevalence of cardiovascular diseases at noise levels as low as 70 dB(A).[9,30] Given the high prevalence of heart disease in Halifax, when compared to similar size cities in Canada, there is a clear rationale to investigate in more detail the level and distribution of noise for the rest of the city.

Certain study limitations may affect the generalizability of the results. First, noise levels were measured in two neighborhoods and within a limited time period. Increasing the number of study areas to include additional land-use types would provide a deeper understanding of the relationship between environmental noise, the built environment, and human health risks. Second, an extended sampling campaign could investigate the potential for seasonal variation on noise levels. For example, the source and character of environmental noise may change with weather and road conditions. Third, the collection of full 24-h samples would help to eliminate

TABLE 5 Study L_{Aeq} values[a] compared to noise exposure limits set by Italian legislation

	Area 1 (residential)		Area 2 (mixed use)	
	Noise exposure limits	L_{Aeq}	Noise exposure limits	L_{Aeq}
Day (06:00–22:00)	55.0	55.4	60.0	63.4
Night (22:00–06:00)	45.0	50.0	50.0	56.1

[a]Expressed in dB(A)

measurement error in the L_{Aeq} calculation. Future research should consider the variation of noise with land use in a similar fashion to air quality research to enable prediction of noise levels in locations without direct noise measurement. This approach could be complemented by interviews with neighborhood residents in order to investigate annoyance and the potential for noise-related human health risks.

Despite these limitations, this study provides important evidence concerning the relationship between land use and environmental noise. A planning strategy focused on mixed-use development may result in an increase in noise levels and human exposures to noise at levels with potential health implications. In a 2007 paper on urban growth and population health, the authors recommended the inclusion of urbanicity as a potential determinant of health.[31] Indeed, our findings suggest a sensitivity of residential areas to noise disruptions from such urban standards as traffic intensification. Municipal planning policies and initiatives should consider integrating traffic restrictions and controls in residential areas and school zones. At present there are no quantitative noise standards on which to compare measured noise levels or evaluate noise exceedances in Halifax, and all excess noise levels are controlled through a complaint driven process based on perceived noise levels. Municipal representatives should consider the institution of new environmental noise standards and policies in order to protect the health of residents and preserve urban environmental quality. Such policies could include improving the quality of mufflers on buses especially in light of findings that relate potentially harmful noise levels to mass transit systems.[32] Ideally, policy development and regulation should originate from sound planning and an inclusive multi-sectoral approach,[33] to protect and improve population health in increasingly urbanized living environments.

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