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The Urban Soundscape: Analysing the Spatiotemporal Distribution of Acoustic Events and its Influence on the Racial/Ethnic Composition of New York City Neighbourhoods

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Abstract

Past research has shown that the effects of prolonged exposure to urban acoustic noise are both detrimental to mind and body. In recent years, studies have also indicated that the socially disadvantaged are more susceptible to environmental hazards such as noise pollution. This paper aims to fill a gap in literature through the evaluation of urban soundscapes by analysing the spatiotemporal patterns of acoustic events within selected New York City (NYC) neighbourhoods and comparing the datum to the socio-economic data of the urban environments. In this paper, the author aims to address this question, ‘Does racial/ethnic composition of each neighbourhood influence how acoustic events are distributed, and in what way does this relate to the socio-economic status of each location?’ This study focuses on seven neighbourhoods within the New York City metropolitan area, each location representing one of the seven levels of noise metadata found on NYC’s 311 noise map. The ambient soundscape of each location was recorded for 30 minutes over four different time intervals across three days, comprising in a total of 45 hours of raw data. Acoustic events were extracted and annotated for saliency and classed according to soundscape components, which were then compared against the racial/ethnic demography of NYC. The findings in this study partially aligned with past research in which communities of lower socio-economic status with higher proportions of non-Caucasian communities were susceptible to higher levels of noise exposure. Additionally, this study also aligned with the hypothesis that high numbers of acoustic events negatively correlate to the socio-economic composition of neighbourhoods.

Keywords: acoustic events, New York City, noise pollution, socio-economic status, soundscape, urban soundscape

Introduction

Soundscape is the musical composition of our world. Much like the more traditional definitions of music and sound, it contains timbre, pitch, duration, loudness, texture, and spatial location. Although it shares similarities, this 'musical composition' is endless, presumably without an end, and once it is heard, it is never heard of the same way again. Listening to music can enhance ones state of being. Listening carefully to our environment can enhance one's life. Our worldly experience is made more interesting as it allows us to use and engage our senses properly; it encourages us to listen a little carefully, enhancing our lives. Our acoustic environment is a collection of sounds from all sources that can be heard by persons occupying a particular space. It is an environment that is shaped by all kinds of different sounds that originate from multiple sources, which are present in space and time. It is also shaped by the modification of sound as it travels from source to listener. How it is shaped is primarily based on the sources that are present, the location of the listener and the conditions along the path of its transmission (Brown, Gjestland, & Dubois, 2016). In the context of an urban space, the acoustic environment is a complex system that links with the physical, psychological and social factors within its immediate community (Farina, 2014). This modification of sound is not limited to only one reflecting surface; multiple reflections may and can occur off various surfaces within the area. The aural experience of the urban acoustic environment is also dependent on the present sound sources, the location of the listener, and the propagation conditions along the path of the sound from source to receiver which then varies according to the time of day, and from one season to another (Brown et al., 2016).

Soundscape can be defined as a combination of sounds that arises from an immersive environment. The sonic information collected within a said space and place refers to both natural and environmental sounds created by humans and can be distinguished into three categories. In the attempt to classify and identify the sounds sources present in our environment, Gage, Ummadi, Shortridge, Qi, and Jella (2004) proposed a system to categorise the origins of all sounds into one of three components: 1) geophony – sounds produced by non-biological natural agents; 2) biophony – sounds produced by living organisms, and; 3) anthrophony – sounds produced by humans and man-made objects.

Community Level Inequality To Estimated Noise Exposure In And Outside Of The United States

The study of noise and its relationship to socio-economic status across communities in the US has been on-going for the past 40 years. The earliest reports of inequality in noise pollution in the US were described in a study by the Environmental Protection Agency (EPA) in the 1970s. It indicated that survey respondents who belonged to communities of higher socio-economic status lived in quiet neighbourhoods and reported lower presence of noise originating from airplanes, traffic, and human vocalisation, but a higher presence of noise from motorcycles, garden power tools and sports cars (U.S EPA, 1977). There is a general assumption that people living in noisy neighbourhoods are from communities that are from the lower income bracket and are more prone to higher crime rates, health problems, and achieve lower educational attainment. But applying the same assumption to more diverse metropolitan areas such as New York City, may not be entirely accurate as illustrated in the Noise Severity Level (NSL) data used in this study that demonstrates high socio-economic status of particular neighbourhoods may not always correlate to lower NSL. In another example, a study by Tamura et al. in 2017, reported links to improvements in body weight and blood pressure of the urban poor to the noisiest neighbourhoods of the city.

In Minneapolis and St. Paul, Minnesota, as well as Montreal in Canada, in both cases, it was found that communities of lower socio-economic status or communities that had a higher proportion of ethnic minorities were exposed to higher noise levels. In Minnesota (Nega, Chihara, Smith, & Jayaraman, 2013), it was reported that there was a significant increase in traffic noise as block group median household income and housing value decreased and the proportion of ethnic minority of residents and those above 18 years of age increased. Spatial models were used in Montreal to estimate the association between race/ethnicity and socio-economic status through modelling the mean 24-hour traffic noise levels in 7,456 city blocks. Here too, it is observed that there was an increase in noise levels as the proportion of low-income and non-white individuals increased (Carrier, Apparicio, & Séguin, 2016).

Similar to this, a study conducted by Casey et al. in 2017, suggested that there was an inequality in the spatial distribution of noise pollution along racial/ethnic and socio-economic lines across the contiguous United States. Multiple indicators of neighbourhood socio-economic context such as poverty, unemployment, linguistic isolation, high proportion of renters and those who did not finish high school, were associated with the increase night and daytime noise. Additionally, neighbourhoods with higher population of African Americans, Hispanics, and Asians were found to have higher noise levels.

There were several studies conducted outside of the US and Canada with mixed results due to their focus, which was more on the socio-economic status as an explanatory variable. In a study conducted at 123 schools near Heathrow Airport in the UK in which they measured the estimated noise exposure, it was reported that in a sub analysis, students that were eligible for free lunches were associated with higher noise exposure (Haines, Stansfeld, Head, & Job, 2002). In Birmingham, UK, a study revealed that there was a weak association between daytime noise levels with higher proportions of Black residents at the enumeration district level (Brainard, Jones, Bateman, & Lovett, 2004).

In Marseilles, France, it was found that census blocks with intermediate socio-economic status had the highest estimated exposure to road noise, whereas in Berlin, Germany, there was no direct link between socio-economic status and noise exposure at the planning unit level (Lakes, Brückner, & Krämer, 2014).

In Hong Kong, Lam and Chan (2006) reported a weak but statistically significant relationship between lower educational attainment and income to higher nose exposure. In Germany (Kohlhuber, Mielck, Weiland, & Bolte, 2006) and Wales, UK (Poortinga, Dunstan, & Fone, 2008), it was indicated that individuals who belonged to lower socio-economic status reported higher levels of neighbourhood noise. Contrary to these findings, a study in Paris, France, found that residents of neighbourhoods with the highest housing values and the highest levels of educational attainment reported the highest estimated noise exposures (Havard, Reich, Bean, & Chaix, 2011).

Disproportionate Exposure and Distribution of Noise Based on Socio-Economic Status and the Influence of Politics

The distribution and disproportionate exposure of noise among communities of different socio-economic statuses is uneven. Some groups are exposed to higher levels of noise when compared to others. Past studies have revealed evidence that suggests a connection between the marginalised and the poor to higher levels of exposure to noise.

Several studies on environmental justice in the US have suggested that the magnitude of exposure to hazardous waste and air pollution is in line with the social gradient in which those who belong to ethnic and racial minority groups, as well as the poor and the uneducated, are exposed to pollution at a greater scale (Mohai and Saha, 2007; Bell and Ebisu, 2012; Hajat, Hsia, & O'Neill, 2015). A recent study has found that there is an inequality in the spatial distribution of noise pollution along racial, ethnic, and socio-economic lines across the contiguous United States in which several indicators of neighborhood socio-economic contact such as poverty, unemployment, linguistic isolation, high proportions of renters in the neighbourhood and those who have not obtained a high school diploma, were associated with an increase in daytime and night time noise. Neighbourhoods with higher proportions of Native American, Asian, African American and Hispanic residents and lower socio-economic status were at the most risk to higher noise exposure (Casey et al., 2017).

The unbalanced distribution of noise among communities can be linked to the imbalances of political power between the poor and the wealthy. In the US, there is an asymmetry in political power along economic, ethnic, and racial lines within highly segregated metropolitan areas because this kind of asymmetry in political power spatially binds minority communities and the working class through the concentration of poverty and the lack of economic opportunity, as well as lending policies and housing development that is highly exclusionary towards these marginalised communities (Massey and Denton, 1993). It is theorized that communities comprised of people of colour and the poor are disproportionately exposed to environmental hazards due to factors which include weak enforcement of regulations in marginalised neighbourhoods, as well as the lack of capacity to engage with people of the community in making decisions on appropriate land use (Pulido, 2000; Morello-Frosch, 2002). This kind of power imbalance can potentially lead to disparities in exposure to environmental hazards such as noise, air pollution and hazardous

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materials because the more influential and powerful residents have the ability to influence decisions about the locations of undesirable land use in ways that are beneficial to their community (Morello-Frosch and Lopez, 2006; Cushing, Morello-Frosch, Wander, & Pastor, 2015).

Evidence suggests that spatial segmentation of neighbourhoods, workplaces and basic service locations due to the Core Based Statistical Area (CBSA) level racial segregation increases vehicle travel miles (Morello-Frosch and Jesdale, 2006) which can potentially contribute to noise pollution. Additionally, the more affluent residents have the monetary means to invest in noise abatement technologies such as air-conditioning, and triple-paned windows. This means that residents of the higher income bracket potentially have lower actual exposure to noise compared to poorer individuals living in neighbourhoods that are exposed to the same estimated levels of noise.

Methodology

Location Selection and Noise Severity Levels

Location selections were made in reference to a publicly available noise map based off noise complaints to NYC311, which is an information hotline that provides all of New York City's government services, as well as complaints.[1] Data was mapped by census tract and it revealed seven levels on the noise gradient. In this study, classical music terms were used to describe each of the seven levels, ranging from *pp* (*pianissimo* – very quiet) to *fff* (*fortissisimo* – very, very loud).

In selecting the locations based on its noise severity level (NSL), as well as its ease of access and walkability, the recordings took place in locations listed in Table 1. For this study, the concept of *noise severity level* is based on the seven-degree scale of noise complaints as reflected in the NYC311 noise map. Each level of NSL is based on the quantity of collected noise complaints within each neighbourhood, independent of its amplitude or source.

Recording Days, Time, Duration and Equipment

Recording for each location was over the course of three days for 5 weeks. Recording days were determined to be carried out on Tuesday, Wednesday and Thursday of each week. These days were considered 'neutral days'. Each day was separated into four Time Windows (TW) to reflect the changes that may occur throughout the day within the same acoustic environment. There was the exception of Governors Island, in which the recording days remained the same but time windows were reduced to three a day. This is due to the limitations in accessibility in which the ferries to and from the island operated from 10:00 a.m. to 6:00 p.m. on weekdays (Table 2).

Table 1

List of recording locations arranged by position of the NSL

NSL	Location (Num.)	Site	AHDI
pp	Nolan Park (L1)	Governors Island	9.062
pp	GI Outlook Hill (L1a)	Governors Island	9.062
p	Prospect Park Chaim Baier Music Island (L2)	Prospect Park	5.109
mp	Marion Hopkinson Playground (L3)	Bedford-Stuyvesant	3.391
mf	Vanderbilt St & Prospect Park Southwest (L4)	Windsor Terrace	4.287
f	Paley Park (L5)	Midtown	8.254
ff	Lincoln Center Plaza (L6)	Upper West Side	8.61
fff	TKTS Times Square (L7)	Midtown	8.254

Table 2

Time blocks for each recording day for all locations

TW	Governors Island	All Other Locations
TW1	10:00 a.m. – 12:00 p.m	.9:00 a.m. – 12:00 p.m.
TW2	1:00 p.m. – 3:00 p.m.	1:00 p.m. – 4:00pm
TW3	4:00 p.m. – 6:00 p.m.	5:00 p.m. – 8:00 p.m.
TW4		9:00 p.m. – 12:00 a.m.

In total, ninety recordings were made, which came up to a total of 45 hours of raw soundscape data. All samples were recorded in 44.1kHz/24 bit on a *Zoom* H4n Pro field recorder. A pair of Ultrasone HFI-450 closed headphones was used for monitoring.

Socio-Economic Data

Data used in this study was sourced from The American Human Development Index (AHDI)[2]. It is a numerical measure made up of what is considered to be the three basic ingredients of human well-being which is based on the human development concept: 1) health; 2) education, and; 3) income. The 2011-2015 American Community Survey (ACS)[3] provided data for racial/ethnic demographics by block group variables. The ACS is a nationwide survey that is designed to provide data on the changes that happen at a community level.

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Acoustic Detection, Annotation and Classification

Detection and extraction of sound events were executed using the Rapid Annotator (Raptor). This software is a MATLAB based sound analysis toolbox (currently unpublished) and it is used for rapid human annotation of sound objects. Raptor was developed as part of the Citygram team (Park and Lin, 2017). Each recording sample produced approximately 1,500 individually extracted acoustic events ranging between one to ten seconds per event. Acoustic events were annotated based on a two-step process in order to decompose the acoustic perception.

The first task was to annotate each event to one of the three saliency levels (background/mid-ground/foreground). In this study, saliency can be described as the relationship of sounds or the combination of, to a single observer that falls into one of the three positions of prominence (back-, mid-, fore-). The second task was to assign and identify each acoustic event to one of the twelve sounds classes which was based on the 10 most commonly reported noise complaints on NYC311 (Table 3), which was then categorised into one of the three soundscape components. In order to determine the density of each individual recording, an extraction of the total number of acoustic events per sound class per audio sample was performed.

Statistical Analysis

Due to the number of samples collected, to ease the calculation process, averages of acoustic events were calculated according to different combinations for each location: 1) average acoustic events (AAE) by total of all days, 2) AAE by total of all time windows, 3) AAE by total per day, and 4) AAE by total per individual time window.

The Pearson's correlation coefficient was used to test the significance of the trend. The measure of the strength of linear associations between two variables is denoted by r-. In this study, r2 was used for the convenience of easing other possible operations. It takes on a range from +1 to -1 in which the value of 0 indicates no correlation between the two variables. A value greater than 0 indicates a positive correlation, a value less than 0 indicates a negative correlation. The correlation strength is determined by the closeness of the value r2 to either +1 or -1, depending on whether the relationship is positive or negative.

Table 3

4 Categories of soundscape components and its sub-classes

Geophony	Biophony	Anthrophony	
1) Rustling leaves/Heavy winds/Water	2) Birds/Insects/Wildlife (chirping, squawking, screeching)	4) Road/Marine traffic (honking, beeping, fog horn)	9) Footsteps, running, crunching, skateboard, bicycle passing
	3) Domesticated animals (barking, whining, panting)	5) Road traffic (passing/idling/engine start/screeching)	10) Music (passing music from car)
		6) Road traffic (siren wailing	11) Human voice (talking, shouting, laughing)
		7) Low flying aircraft	12) Other (unidentifiable events, night time ambiance)
		8) Banging, construction noise, machines, vents, sprinklers	

Results and Analysis

Based on past studies of noise exposure and its relationship to race/ethnicity, it was found that census blocks of lower socio-economic status with higher proportions of non-Caucasian/white ethnicities were susceptible to higher levels of noise exposure across the contiguous United States.

For the purposes of this study, race/ethnicity categories were arranged to include the major racial groups as such: 1) Caucasian/White; 2) African American/Asian; 3) Native American/Others. This is because analysis of more detailed ethnic groups and sub-groups returned inconclusive results and this form of grouping produced better correlations.

In this study, it was found that the increase of acoustic events were in line with the hypothesis, where by higher acoustic event averages resulted in a percentage population increase of non-white ethnicities. This study has also indicated that the correlation between low average acoustic events to a higher percentage of Caucasian/White is strong. This means that the higher the number of Caucasian/White groups in a neighbourhood indicates a decrease in acoustic event average among these eight New York City locations.

Figure 1, Figure 2 and Figure 3 have been arranged in such a way to include a third variable, the AHDI. This has been done by colour coding the data points. The

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trend line will remain as it can serve as a general marker to how the two variables within the 2D space interact. As for the correlation for AHDI in the 3D space, this can be seen relatively clearly by the colour gradients as illustrated in these graphs. The relative vertical change in colour can be compared to the relative horizontal change in colour to aid in visualising any patterns within the data. The colours used, range from a white to dark orange, where white indicated a low AHDI (based of the minimum value of 3.391), and the dark orange indicates a high AHDI (based off the maximum value of 9.06). With this in mind, by looking at all three graphs, there is a clear pattern that as the average acoustic events increases, the AHDI is expected to fall. These graphs showing the proportions of racial demographics help paint a clear picture if any one racial group is affected by the change in average acoustic events and the AHDI.

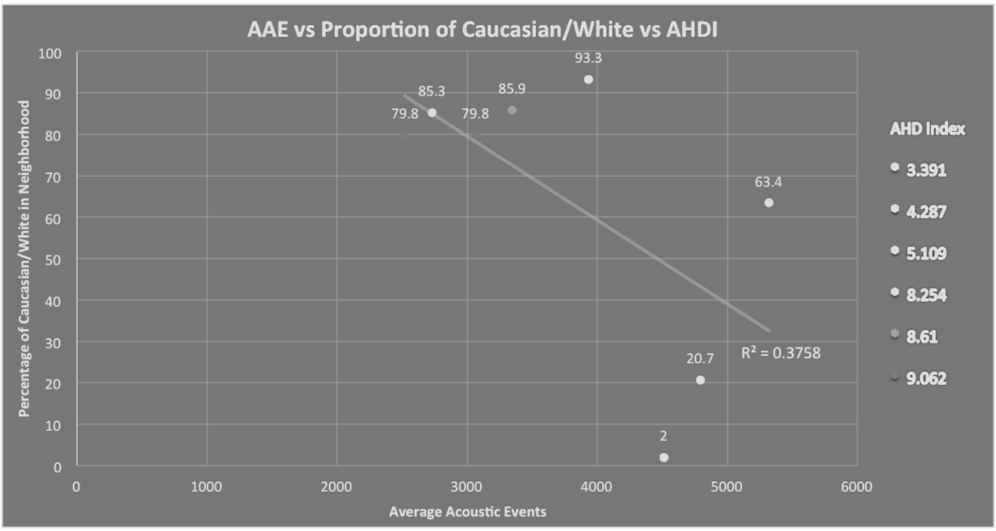

Figure 1. Percentage proportions of Caucasian/White ethnic group to Average Acoustic Events (AAE) and The Measure of America's 2014 American Human Development Index (AHDI) per neighbourhood.

Figure 2 demonstrates a strong correlation between the increase in average acoustic events to the increase in percentage proportions of African American and Asians (R2 = 0.45659) as well as a decline in the AHDI. Figure 1 on the other hand, there is a strong correlation between an increase in average acoustic events to the decrease in the percentage population of Caucasian/White (R2 = 0.3758) resulting in an increase in the AHDI. An increase in acoustic event occurrences results in the decrease in population percentage in Native American/Others group (R2 = 0.16836) although in this case, there seems to be only a weak correlation in the AHDI reduction as there is no incredibly clear progression of a light to dark coloured AHDI indicator or vice versa, as illustrated in Figure 3. This was further confirmed in Figure 4 in which the population percentage of Native American/Others group was plotted against the AHDI to reveal a weak trend line (R2 = 0.02097) thus confirming that the percentage population of this group has little to no effect on the AHDI.

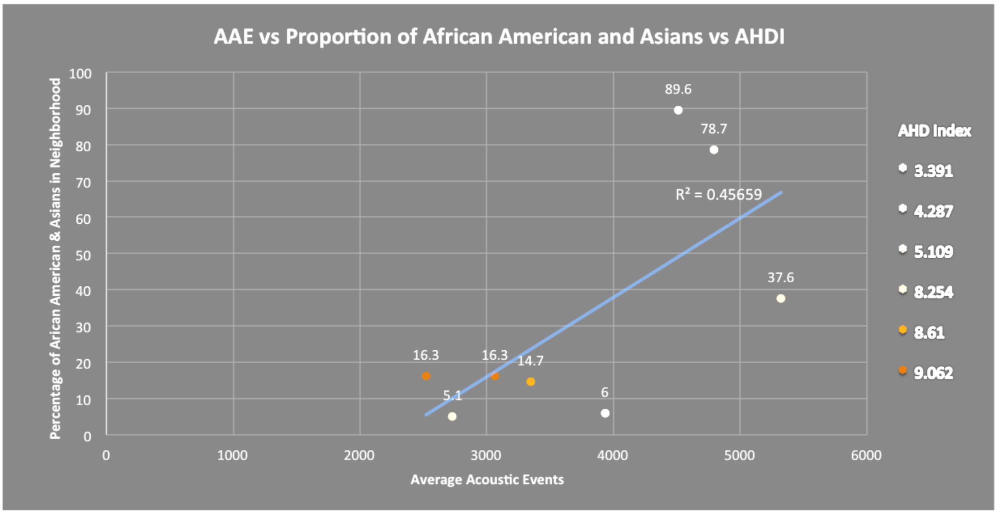

Figure 2. Percentage proportions of African American and Asians ethnic groups to Average Acoustic Events (AAE) and The Measure of America's 2014 American Human Development Index (AHDI) per neighbourhood

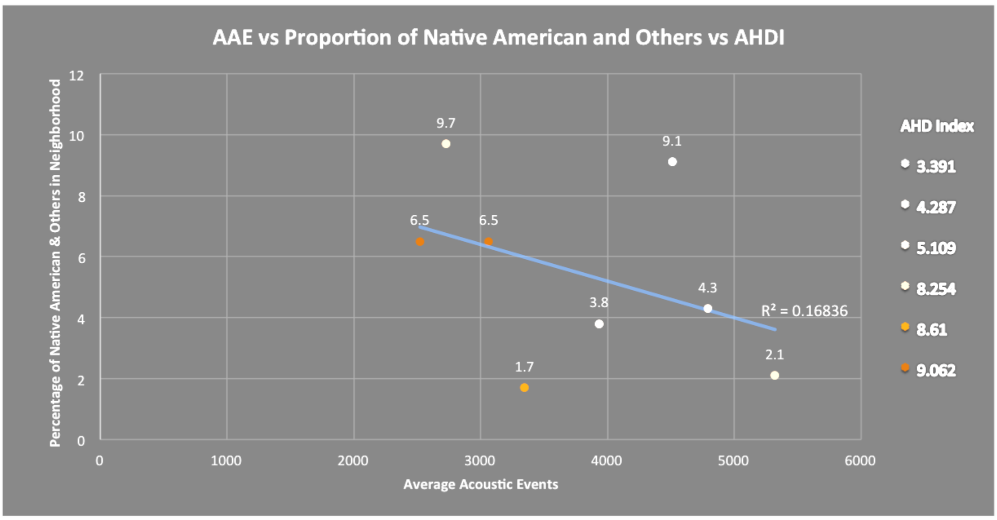

Figure 3. Percentage proportions of Native Americans and Others ethnic group to Average Acoustic Events (AAE) and The Measure of America's 2014 American Human Development Index (AHDI) per neighbourhood

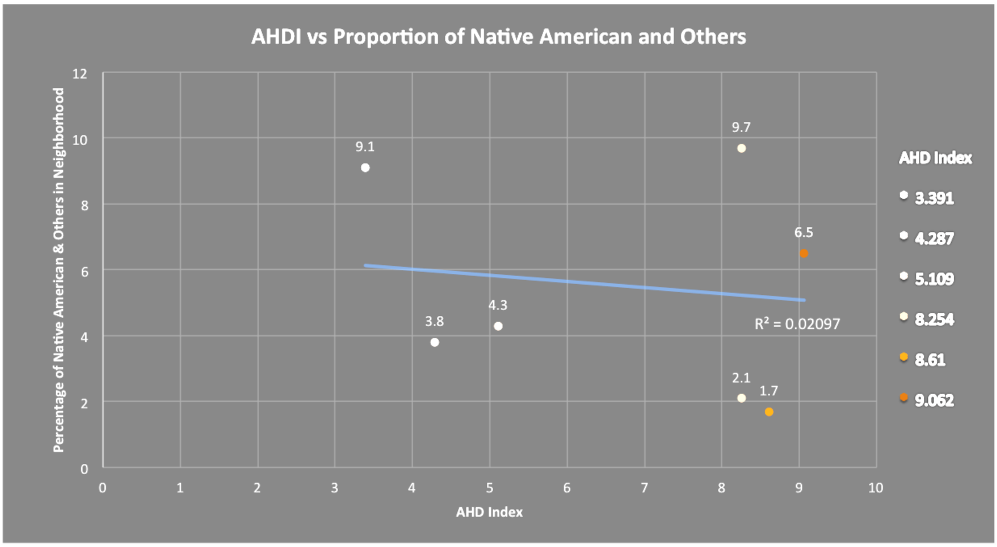

Figure 4. Percentage proportions of Native Americans and Others ethnic group to The Measure of America's 2014 American Human Development Index (AHDI) per neighbourhood

As for the vertical component which is population numbers of race/ethnic groups, the same trend seems to be present here as well – as the population numbers go up, the AHDI reduces. In summary, the AHDI of each neighborhood is affected by the number of acoustic events recorded as well as the population percentage in both the Caucasian and the African American/Asians group, but in the Native American/Others group, the increase or decrease in percentage population between neighborhoods does little to influence the increase or decrease in AHDI.

Discussion and Conclusion

In observing the relationship between the distribution of acoustic events and the socio-economic status, the collected data demonstrates that urbanites living in neighbourhoods on the lower end of the AHDI spectrum were exposed to increased occurrences in acoustic events. In terms of racial/ethnic composition of neighborhoods, findings revealed that in most cases, as the proportions of non-white ethnicities and the number of average acoustic events increased, the AHDI of these neighbourhoods decreased. This aligned with past studies in which communities of lower socio-economic status with higher proportions of non-white communities were exposed to higher noise levels.

Several studies in the past found that communities who belong to a lower socio-economic status which had higher proportions of ethnic minorities were exposed to higher noise levels (Nega et al., 2014; Carrier, Apparicio, & Séguin, 2016; Kohlhuber et al., 2006; Poortinga et al., 2008). This study produced similar findings in which the increase of average acoustic events resulted in an increase of non-white proportions with lower AHDI. In the case Native American/Others, the opposite affect was found in which the increase of acoustic events resulted in a decrease in this group of non-white individuals but in relation to the AHDI, correlations were not strong and the percentage population of this group has little to no affect on the AHDI. This is in partial contrast to a study by Casey et al., (2017) in which it was determined that neighborhoods with higher populations of African Americans, Asians, Hispanics and other minority groups are exposed to higher noise levels. These findings are quite possibly caused by the very small proportions of this non-white ethnic group within the locations in question for this study, therefore their affect is minimal.

In summary, the collected data demonstrated that 1) urbanites living in neighborhoods on the lower end of the socio-economic spectrum were exposed to increased occurrences of acoustic events; 2) the increase in proportions of non-white ethnicities correlated with the increase of acoustic events, which in turn decreased the overall AHDI standing of these neighbourhoods, in most cases; 3) a geographical expansion for future studies would allow for a more accurate representation of the relationship between urban soundscape and its socio-economic factors.

Urbanisation is expanding rapidly and this means exposure to noise pollution that can have detrimental effects on human health and body, which can result in increased stress, blood pressure, heart rate, cardiac output (Evans, Hygge, & Bullinger, 1995; Lercher, 1996), diminished capacities in neurocognitive functions, mood disorders and neurodegenerative diseases (Tzivian et al., 2015), cardiovascular disease (Gan, Davies, Koehoorn, & Brauer, 2012), hypertension (van Kempen and Babisch, 2012), and behavioral problems in children (Hjortebjerg et al., 2016).

Although there are several noise abatement methods in place such as laws and noise regulations that have been enacted in several countries throughout the world, these laws are based on definitions of excessive noise in terms of volume and manage sounds as waste. In order to fully understand our urban acoustic environment and how it affects our quality of life, the author hopes that the findings in this research study will fill a gap and add to the existing literature by introducing another dimension to soundscape studies for the purpose of improving the standards of living of urban communities.

This paper is part of a larger project and a web-based repository was created to better represent the data to a larger audience through an interactive platform. For a more in-depth look at the data collected for this study in its entirety, this website can be viewed at http://urban-soundscapes.com.

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Endnotes

[1] Mapping last year's 311 noise complaints. Retrieved from http://bl.ocks.org/nerik/raw/90c087a3f0fe96f8a2ce/#13/40.7620/-73.9667
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Biography

Shuraifa Asmah Shad Saleem Faruqi earned her Master of Music in Music Technology from the Steinhardt School of Culture, Education and Human Development at New York University. Additionally, she holds both a Diploma in Music and a Bachelor in Music Performance (Hons.) from Universiti Teknologi MARA (UiTM). Having had the opportunity to experience the cacophony of city life in both Kuala Lumpur and New York City, her interest lies in the study of urban soundscapes and its impact on the urban dwellers quality of life. Her current focus is on the analysis of spatiotemporal patterns and soundscape components of the urban acoustic environment, and its relation to the socio economic and racial/ethnic demography of metropolitan cities, with the hopes of improving the urbanites standard of living as well as to preserve its sonic heritage.