Burden of Disease from Traffic Noise Quantification of Healthy Life Years Lost in Toronto, Canada

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Burden of Disease from Traffic Noise Quantification of Healthy Life Years Lost in Toronto, Canada, Benjamin Simak, Master of Spatial Analysis, Ryerson University, 2020

Abstract

This paper explores how traffic noise in Toronto can lead to Ischemic Heart Disease (IHD), high levels of annoyance, and high levels of sleep disturbance. Local traffic noise data was combined with methods for predicting how daytime (Lden) and nighttime (Lnight) decibel levels impact years of life lost (DALYs) as a result of the heath outcomes. The methods were borrowed from European studies as there has yet to be any North American studies on this public health issue. The result for Toronto was a total of 28,380 annual DALYs, meaning this number of years of healthy life were lost as a result of traffic noise in Toronto causing IHD, high levels of annoyance, and high levels of sleep disturbance. A geographic information system (GIS) was used to spatially analyze the traffic noise and see where the high decibel levels were located as well as where concentrations of DALYs for each health outcome were located across Toronto at a dissemination area level. The goal of this paper is to highlight the importance of environmental noise pollution as a public health issue for Toronto and North America more generally, demonstrate how to calculate noise levels into a burden of disease metric, and provide spatial insights at a local scale to aid in addressing the health impacts of noise.

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1.0 Introduction

Noise and its effects on hearing have been studied for decades. In fact, noise-induced hearing loss (NIHL) has long been recognized as an occupational disease, amongst copper workers from hammering on metal, blacksmiths in the 18th century, and shipbuilders or "boilermakers" after the Industrial Revolution. It is the reason there are laws in place for workplace noise allowances, bylaws limiting noise on evenings, mornings, and holidays, and the reason why headphones have caps on noise levels. The primary concern has been the cumulative effects of intermittent high decibel level noise exposures to one's delicate ears. New development on long term noise exposures at much lower levels have become a major concern for public health, especially in Europe. In fact, long term noise pollution has been known to cause major long-term health problems that could result in premature death and debilitating disabilities. Noise pollution is ranked second among Environmental Public Health concerns by the WHO only exceeded by air pollution (World Health Organization, 2011). In depth research on Environmental noise pollution has been primarily studied in Europe, although a small number of studies have measured noise or developed environmental noise models at the scale of cities in the United States and Canada (Allen et al., 2009, Tetreault et al., 2013, Lee et al., 2014; Ragettli et al., 2016, Zuo et al., 2014, Oiamo et al. 2018, Liu et al 2019). All the studies from North America either discuss the correlation between noise pollution and air pollution or explain a method for modeling traffic noise data and presenting findings on decibel levels across the study areas. Although noise pollution and its effects on human health have been known as early as the 18th century, it has only started being recognized as a major public health issue as early as the 1980's and 1990's due to advances in technology and modeling capabilities. Health cohort studies for problems such as cardiovascular disease relating to noise exposure became more prevalent and with noise exposure models and predictions being developed due to increased accessibility to transport data allowed for large scale studies to finally be unravelled. This research paper seeks to take this noise data further and uses methods to measure the healthy years of life lost due to traffic noise. This is something that has yet to be done in a North American study. More research is needed to understand how dominant noise sources, built forms, and urban morphologies typical of North American cities influence noise levels, and consequently population exposures. Considering environmental noise pollution is a major health risk to everyone, especially those in urban areas, and with the fewest available studies done in Canada, it seems of utmost importance to conduct a study like this in the largest city in Canada.

1.1 Study Area

Toronto is the largest city in Canada with a population of 2,757,932 and a land area of 630.2 km^2 (Statistics Canada, 2017). The overall population density is 4,377 per km^2, but this ranges from well over

20,000 per km^2 in the densely populated urban core to less than 2,000 per km^2 in suburban neighbourhoods (Oiamo et al., 2018). The city has experienced a population growth rate significantly higher than the national average in recent years and the majority of this growth is absorbed by high-rise apartment buildings in central areas of the city (Statistics Canada, 2017). With this growth, there is an even larger population that is at risk for health issues caused by excessive noise. Europe has recognized and actioned the study of environmental noise pollution on human health and gathered strong evidence as to why it is a major problem to the public in need of action plans for monitoring and regulating. North America has few studies on noise pollution and heath effects from long term exposure and most of the laws are aimed at the effects to hearing loss and workplace. The North American context needs to have more focus as Europe can be very different in terms of urban design and even the population's general sensitivity to noise may vary across different areas (Oiamo et al., 2015).

1.2 Objective

This research aims to bring attention to the problem of noise pollution in a North American context. Specifically, in Toronto, Canadas largest city. By utilizing traffic noise data from a local study in Toronto, and borrowing methods that are currently being utilized in Europe to quantify the effects of traffic noise on Ischemic Heart Disease, Annoyance, and Sleep Disturbance; this study hopes to provide results in the form of Disability Adjusted Life Years or (DALYs) which is a metric used in burden of disease studies. Canada already has burden of disease studies for various other environmental pollutants, such as air pollution, but despite the fact that research shows noise is a major public health risk, noise monitoring and quantification has not yet been incorporated in a North American burden of disease study. The goal is to showcase what current quantification methods in Europe can tell us about Toronto as a case study using local traffic noise data. It is vital to understand further the effects that noise has on public health in urban environments that are ever growing larger and louder.

2.0 Literature Review

In this chapter, an overview of the types of pollution, how noise is measured, and the health effects due to noise will be discussed in depth. Based upon the body of research relating to noise pollution and heath outcomes, there is a large gap in research for long term health outcomes due to noise in a North American context. The primary sources are found in Europe where environmental noise pollution has been taken seriously as a public health issue and methods for quantifying the effects of noise on the population's health have been developed.

2.1 Types of Noise Pollution

Environmental noise is considered to be any unwanted sounds created by human activity (Murphy & King, 2014). Environmental noise can be broken down into four categories which includes transport sources (road, rail, and air traffic), construction and industry (stationary construction vehicles, A/C Units), community sources (neighbours, bars, radio, television), and social and leisure sources (concerts, firearms, snowmobiles etc.) (World Health Organization, 2011). Noise is a major environmental issue, particularly in urban areas, affecting a large number of people. Environmental noise has been shown to cause and contribute to health issues and thus can be considered a type of pollution, an element that can be regulated, controlled and mitigated (Toronto Public Health, 2017).

Noise is a complex phenomenon to measure as it has several important properties. This includes loudness (intensity, measured in decibels on a logarithmic scale [dB or dBA]), duration (continuous, intermittent, or impulsive), and frequency (pitch) (Toronto Public Health, 2017). The A-weighting curve has been widely adopted for environmental noise measurement and is standard in many sound level measuring devices. A-weighting is an international standard IEC61672:2003 (International Electrotechnical Commission). The A-weighting is applied to instrument-measured sound levels to help account for the relative loudness perceived by the human ear. This process essentially lowers the weight that very low, and very high frequencies are recorded at because those decibel levels are not usually heard by the average person. This is a common scale applied to decibel readings when trying to asses overall health risks due to noise pollution. In environmental noise and health research the focus tends to be on average noise levels for a specific period (day, night or 24 hrs) and measured in dBA. Since the decibel is a logarithmic unit, a sound received by the ear at 60 dBA is perceived as twice as loud as sound at 50 dBA (Toronto Public Health, 2017).

In practice, it is almost impossible to consider noise exposure from all sources when doing a health risk assessment as some exposures are difficult to estimate at the population level. An example of this would be leisure noise through attending music concerts or listening to personal music devices. (World Health Organization, 2011). However, with technology innovations and the cost of electronics becoming less expensive, there have been some new development with personal devices that can track noise exposures at an individual's level. A prime example of this is a new function with Apple Inc. smart watches, is a noise app that measures the ambient noise levels in the environment around the person wearing it and for the duration they experienced it (Apple Inc, 2020). These new integrations of noise monitoring could help get much more granular and contextual noise exposure data which could aid in burden of disease studies such as this. The most common sources of noise pollution that are studied for their health effects include traffic, rail, and air traffic noise as these tend to be the most consistent sources of noise affecting the largest number of people. Based on the Environmental Burden of Disease study in Europe by the World Health Organization, which measures various types of environmental pollution, traffic noise was ranked second among the selected environmental stressors evaluated in terms of their public health impact in six European countries (World Health Organization, 2011). Additionally, the trend is that noise exposure is increasing in Europe compared to other stressors such as second-hand smoke, dioxins, and benzene which are declining (World Health Organization, 2011).

For this study, traffic noise will be the only source used in measuring the effects of noise in the city of Toronto. This is because the data is more easily accessible and traffic noise affects the most people when compared to all other sources of environmental noise (World Heath Organization, 2011).

2.2 Measuring Noise Pollution

Environmental health risk assessment can be based on the Environmental Burden of Disease (EBD) methodology using the metric Disability-Adjusted Life Years, or DALY (World Health Organization, 2000). The EBD combines the concepts of potential years of life lost due to premature death plus equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability. Estimation of EBD for road traffic noise requires knowledge of the distribution of exposure to noise in the population, an exposure-response relationship for each health outcome of interest, and an estimate of a disability weight (DW) for each outcome. Disability weights allow non-fatal health states and deaths to be measured under a common currency. Disability weights allow time lived in various health states to be valued and quantified. Weights that are commonly used for calculating disability adjusted life years (DALYs) are measured on a scale of 0 to 1 where 1 represents death and 0 represents ideal health (Brown, 2015). The disability weights are derived from a series of questionnaires through face-to-face, telephone, and web-based, which asked 30, 230 respondents from Eastern, Southern, Central, and Northern Europe. These questionnaires had scenarios created for over 255 health states, including annoyance and sleep disruption, and respondents rated strongly different health states would affect them. With the thousands of responses, a general disability weighting factor can be derived and used to associate health states to how much of a burden they are to someone living with it (Haagsma, 2015). Studies such as by Tobollik et. al (2019) use the burden of disease methodology to provide an overview of how many years of life are lost due to noise exposure from road, train, and air noise exposure in Germany. The model being used in this paper will take into account three health outcomes, Ischemic heart disease, sleep disturbance, and annoyance in the calculation in relation to traffic noise.

There are a number of noise indicators that need to be collected and used in studies regarding environmental noise and effects on human health. These indicators are part of the International Organization for Standardization (ISO) 2016 guidelines for noise. The most important indicators include

Lden and Lnight. The Lden indicator is an average sound pressure level over all days, evenings and nights in a year (European Environmental Agency, 2010). This compound indicator was adopted by the European Union in the Environmental Noise Directive which dictates the guidelines for collecting and processing noise pollution data (European Commission, 2002). The Lden in decibels (dB) is defined by a specific formula, where: Lday is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the day periods of a year; Levening is the A-weighted long-term average sound level with a 5 dB penalty as defined in ISO 1996-1: 2016, determined over all the evening periods of a year; and Lnight is the A-weighted long-term average sound level with a 10dB penalty as defined in ISO 1996-1: 2016, determined over all the night periods of a year (ISO, 2016). A study by Oiamo et al. (2018) titled, "A combined emission and receptor-based approach to modelling environmental noise in urban environments" mapped traffic noise across Toronto with a predictive model. The study was able to combine emission and propagation-based prediction of traffic noise, the predominant source of noise at the level of streetscapes and the land use regression model to help validate the major sources of noise. The model explained roughly 77% of the traffic noise in Toronto across the different indicator time periods and with high confidence ($p<0.001$) across all indicator time frames (Oiamo et al., 2018). This method can be used to estimate a different noise pollution types, including traffic emissions in this case, and is validated by setting up noise monitors across the city to get exact dBA measures.

Exposure Response curves also known as dose-response relationships provide a way to describe the magnitude of a response of an organism as a function of exposure from a stimulus (Miedema, 1998). The burden of disease from annoyance and sleep disturbance is quantified by using the exposure-response function to quantify the percentage of people feeling highly annoyed (%HA) or highly sleep disturbed (%HSD) due to certain average noise exposure. Exposure-response relationships for annoyance with road traffic noise have been estimated over many decades. There has been considerable variation in the results of individual studies and various syntheses have been performed. The most recent meta-analysis was by Miedema and Oudshoorn (2000) examining twenty-six studies from six European countries and Canada, consisting of a total of 19,172 individuals. Exposure response curves are used when primary research is not available for a study area. Although the annoyance and sleep disturbance can be subjective, the work by Miedema and Oudshoorn provides a way to apply these responses to different populations with confidence that it has been seen across multiple countries and people. Although this study was done two decades ago, it is the most complete noise exposure response available and will be used for the case study in Toronto. Exposure response curves are used because it is costly and time intensive to collect the data for all areas of interest.

2.3 Health Effects from Noise Pollution

Environmental noise pollution can cause a variety of health issues for humans. There are direct and indirect pathways that noise exposure can lead to health outcomes. A paper by Munzel et al. (2014) describes how noise can directly cause problems such as hearing loss and sleep disturbance, as well as indirectly causing issues such as disturbing everyday activities like communication, cognitive functions, and emotional responses like states of being annoyed. Both pathways merge as they inherently lead to increased stress levels. Stress is a common and interrelated state that can initiate risks in the bodies systems. High levels of stress which can be caused as a result of noise exposure lead to factors such as increased blood pressure, blood glucose levels, cardiac output, and a variety of other responses which has a direct effect on cardiovascular health (Munzel, 2014). It is vital to understand that the health outcomes described in this project are interrelated through stress as a response to noise exposure. After eight systematic literature reviews on the effects of noise were conducted as a part of the Environmental noise guidelines for the European region, the health effects that were viewed as critical include cardiovascular disease, annoyance, effects on sleep, cognitive impairment, hearing impairments, and tinnitus (World Health Organization, 2018). Health effects that have not been studied in depth yet and have been called noncritical include the potential for adverse birth outcomes, quality of life, wellbeing, and mental health and finally, metabolic outcomes (World Health Organization, 2018). These health effects are resulting from a mix of sources but generally limited to studies showing contributions from traffic, rail, and air. The evidence on the association between traffic noise exposure and health outcomes in the WHO Environmental Noise Guidelines showed low to moderate quality, however traffic noise had the overall highest quality of evidence when compared to aircraft or railway noise. For this study the primary responses due to traffic noise are explored.

Cardiovascular disease includes Ischemic Heart Disease (IHD) and Hypertension. According to the most recent burden of disease studies hypertension is considered only a risk factor for diseases (Kamp I.V. et al., 2018). For this reason, only Ischemic heart disease will be used in the assessment. Cognitive impairment is omitted as it is unable to be quantified using the DALYs equation method that was used in this study. Finally, hearing impairments and tinnitus are not included in the burden of disease assessment as they are generally a result of leisure activities such as attending loud night clubs and using personal headphones. As this assessment is on the effects of road noise on health, these health outcomes are not included. The EU Environmental Noise Directive (2002/49/EC) also did not include leisure noise in their assessments.

According to the WHO 2018 Noise Guidelines the scientific evidence reviewed and summarized in the report imply that the health outcomes from road traffic noise including incidence of Ischemic Heart

Disease, annoyance and sleep disturbance can be quantified in a health risk assessment, and that their effects are cumulative (World Health Organization, 2018). The goal of this paper will be to quantify the burden of disease in Toronto due to traffic noise using these three main health effects. It is important to note that care should be taken to avoid "double counting" when DALYs from different outcomes are totalled to estimate an overall burden of disease from an environmental risk factor. In the case of environmental noise, this should not be a big problem. For example, the burdens of annoyance during the daytime and sleep disturbances at night can be safely added up.

2.3.1 Cardiovascular Disease

For this study the primary cardiovascular disease that will be discussed is ischemic heart disease. According to the American Heart Association (2019), ischemic heart disease is the term given to heart problems caused by narrowed heart arteries. When arteries are narrowed, less blood and oxygen reaches the heart muscle. This is also called coronary artery disease and coronary heart disease. This can ultimately lead to heart attack.

Noise exposure has been linked to cardiovascular diseases as vascular tension is impacted by stress responses (Babisch et al. 2005 & Bodin et al. 2016). These effects have been reported to occur at levels ranging from 55 to 73.6 dBA outdoors. A higher arousal of the autonomous nervous and endocrine systems, which is adversely influenced by road traffic noise exposure, is associated with an increased risk of mortality from ischaemic heart disease (World Health Organization, 2011). Recio and colleagues (2016) found a 2.9 percent increase in the risk of death from ischaemic heart disease for every 1 dBA increase in nighttime noise levels between 58.7 – 76.3 dBA (Lmax night) for people 65 and older. For people younger than 65, there was an 11 percent increased risk of death from ischaemic heart disease for every 1 dBA increase in average nighttime noise levels between 56.2 – 69.9 dBA (Recio et al., 2016)

It is clear that road traffic noise has an effect on cardiovascular health in humans due to the extensive research done over the past decade showing strong correlation. In the World Health Organizations "Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary" (2017), It was stated that, the most comprehensive evidence was available for road traffic noise and ischemic heart diseases (IHD) which combined a result of 7 longitudinal studies revealed a relative risk (RR) of 1.08% (95% CI 1.01-1.15) per 10DB (Lden) between the ranges of 53dB – 80dB (Lden) for the association between road traffic noise and the incidence of IHD. IHD will be used as the cardiovascular outcome due to traffic noise in Toronto as it has the strongest literature backing its relationship (World Health Organization, 2011).

2.3.2 Annoyance

Annoyance to noise results in a multitude of emotional responses including "disturbance, dissatisfaction, displeasure, irritation, nuisance, or anger" (Van Kempen & Van Kamp, 2005). To date, most assessments of the problem of environmental noise have been based on the annoyance it causes to humans, or the extent to which it disturbs various human activities (World Health Organization, 2011). Although annoyance is not clearly classified as a health outcome, it does affect the well-being of many people and therefore may be considered to fall within the WHO definition of health as being “a state of complete physical, mental and social well-being” (World Health Organization, 2011). According to the Guski et al., (2017) article, annoyance response has three elements which rationalize it as a health concern. First, there is repeated disturbance due to noise (repeated disturbance of intended activities, e.g., communicating with other persons, listening to music or watching TV, reading, working, sleeping), and often combined with behavioral responses in order to minimize disturbances. Then there is an emotional/attitudinal response (anger about the exposure and negative evaluation of the noise source). Finally, there is a cognitive response such as the distressful insight that one cannot do much against this unwanted situation. The multi-faceted response is seen by many researchers as a stress-reaction involving an environmental threat and individual physiological, emotional, cognitive, and behavioral responses which can partly be remembered and be integrated into a verbal long-term annoyance response (Guski et al., 2017). The 2018 WHO Noise Guidelines estimated 45dB – 80dB outdoors as the point at which individuals exhibit high levels of annoyance when exposed to road traffic noise (World Health Organization, 2018).

2.3.3 Sleep Disturbance

Sleep disturbance is one of the most common complaints raised by noise-exposed populations, and it can have a major impact on health and quality of life. Studies have shown that noise affects sleep in terms of immediate effects (e.g. arousal responses, sleep stage changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g. sleepiness, daytime performance, cognitive function deterioration) and long-term effects (e.g. self-reported chronic sleep disturbance).

The auditory system is continuously analysing acoustic information, which is filtered and interpreted by different cortical and sub-cortical brain structures causing acute responses of the autonomic nervous and the endocrine system, even during sleep. Long-term noise stress can adversely affect biological risk factors due to chronic dysregulation. Considering this pathway, noise must be viewed as an environmental risk factor.

Although recent epidemiological studies have shown stronger relationships of nocturnal noise exposure (Jarup et al. 2008) with negative health consequences compared to daytime noise exposure, studies directly investigating the link between acute noise-induced sleep disturbance and long-term health consequences need to be studied further. However, disturbed sleep has immediate next-day consequences (e.g., increased sleepiness, impaired cognitive performance) that may increase the risk for errors and accidents, and thus sleep deserves protection from noise even in the absence of a direct link to long-term health consequences (Basner & McGuire, 2018). It is plausible that preventing acute effects of noise on sleep will likely also prevent long-term negative health consequences.

According to the World Health Organization 2018 Guidelines, about 2% (95% CI: 0.90–3.15) of the population in the study was characterized as highly sleep-disturbed at Lnight levels between 40dB and 65dB. The association between road traffic noise and the probability of being highly sleep-disturbed was an overall risk of 2.13 (95% CI: 1.82–2.48) per 10 dB increase in noise. These findings were a result from a systematic review done by Basner & McGuire (2018) which took 12 studies with a total of 20,120 participants and synthesized the sleep disturbance results from questionnaires about sleep and how noise affects sleep. The 2018 guidelines and exposure response curve will be used in this study when looking at sleep disturbance in Toronto as it is the most documented and robust way to measure sleep disturbance when there are no firsthand studies done in the study area.

3.0 Methodology

As North American studies on the effects of environmental noise on human health are limited, the goal of this study is to use the best methods developed and used currently in Europe, to measure the effects that traffic noise pollution has on human health in a North American context, specifically in Toronto. The research questions were as follows: What is the burden of disease measured in Disability Adjusted Life Years (DALYs) due to traffic noise in the city of Toronto? What areas in Toronto experience the most and least DALYs due to traffic noise?

3.1 Toronto Traffic Noise Model

The modelling of noise decibel data utilized in this study are described in detail in Oiamo et al. (2018). This study was able to provide the average decibel readings at the most exposed facade for more than 600,000 buildings in Toronto. The Lden and the Lnight levels were the specific data used in the exposure response curve equations in order to find the days of life lost due to health outcomes associated with traffic noise. The number of people exposed to each category of traffic noise in Toronto was determined based on predicted façade levels and the number of people in each building, which was estimated based on building size and census dissemination block population data.

3.2 Burden of Disease: DALYs

The flow chart below in Figure 1 can be referenced to help understand the process through the methodology for calculating the Burden of Disease (DALYs) as it is explained in this section of the report.

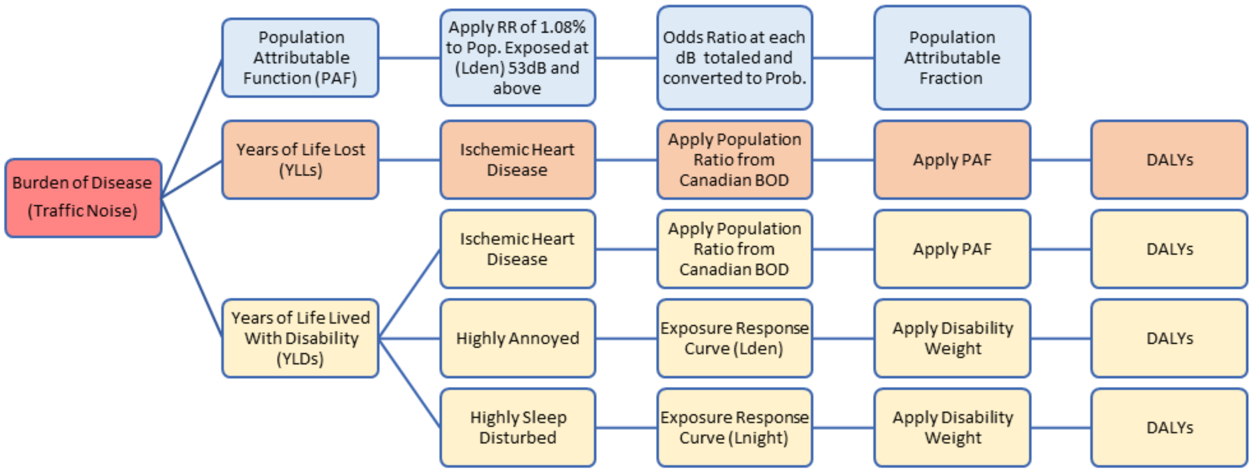

Figure 1: Methodology flowchart for calculating overall burden of disease (DALYs).

The burden of disease equation is expressed in DALYs (Disability Adjusted Life Years) for the population. This measure of population health combines mortality and morbidity in a single metric quantifying the burden of disease in healthy life years lost. Mortality effects are expressed in years of life lost due to premature mortality (YLLs) and quantified by multiplying the number of deaths in a certain age group by the remaining life expectancy at the age of death. For the oldest age group (90+ years) the life expectancy for the age group 90 to 94 years is used (Tobollik et al., 2019). For this study, deaths from ischemic heart disease will be factored in the YLL component of the calculation as this is the only health outcome that can directly cause death. Morbidity, expressed as years lived with disability (YLDs), is quantified by multiplying the number of prevalent disease cases or the number of people affected by a health condition with the corresponding disability weight. In this study, the health conditions include those living with ischemic heart disease, people highly annoyed by traffic noise, and those highly sleep disturbed due to traffic noise. Disability weights are weighting factors for the severity of diseases on a scale from 0 to 1. Zero is representing a status of full health whereas one is understood as a state comparable with death (Devleesschauwer, 2014).

The Global Health Data Exchange provides information on countries state of health. The Burden of Disease for Ischemic Heart Disease for Canada as a country is available on this database. The Disability Adjusted Life Years metric was downloaded and used in order to deduce the DALYs due to IHD in a Toronto Context. The population ratio between Toronto and Canada's population was calculated and applied to the 2017 Canadian burden of disease due to Ischemic Heart Disease to get an estimate of the DALYs due to IHD in the Toronto population. This method assumes that the Canadians general health and rates of IHD are the same as the Toronto scenario population for this study. This method was used as there was no accessible data on IHD for Toronto in an open source.

3.3 Relative Risk and PAF: Ischemic Heart Disease

To calculate the DALYs associated with IHD there are 3 steps that were taken. First, the number of people exposed at each Lden decibel level were taken from the noise model mentioned above. The lower noise exposure threshold for IHD health outcomes were shown to be 53db in the WHO meta-analysis. At 53db and above, the relative risk factor which was taken from the, "WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary, 2018" found a RR of 1.08 (95% CI: 1.01–1.15) per 10 dB (Lden) for the association between road traffic noise and the incidence of IHD within the range of approximately 53–80 dB Lden. This relative was converted into the relative risk at each decibel level. This was then applied to the population exposed at 53 dB and above at each dB increment. The proportion of the population exposed was multiplied by the relative risk at each dB to get an odds ratio at each dB level. These odds were summed up and the result was 1.11 odds ratio or 11/100. This means there is a 11 in 100 odds that those who have IHD or have died from IHD can attribute it to traffic noise at 53dB and above. In order to apply this fraction to the total population affected by IHD in Toronto, the odds ratio is converted into a probability which ends up being 9.86%. The third step is to apply the PAF probability to the 2017 IHD DALYs in Toronto that were deduced form the Canadian overall burden of disease study. The PAF is the percent of those affected by IHD due to traffic noise specifically.

3.4 Exposure Response Equation: Annoyance and Sleep Disturbance

Three steps were also taken to calculate the DALYs for annoyance and sleep disturbance. First, the population exposed at different Lden for annoyance and Lnight for sleep disturbance were determined. The threshold for those experiencing a high amount of annoyance due to traffic noise is shown at Lden 45db and above. The threshold for those experiencing a high amount of sleep disturbance occurs at Lnight 40db and above. The second step is to use an exposure response equation which is an equation created through systematic synthesis of similar studies which results in a regression equation for the relation between annoyance and traffic noise levels and sleep disturbance and traffic noise levels. The equation to find the population that is highly annoyed by traffic noise is from the study by Guski et al. (2017), which was part of the World Health Organization Systematic Review of Environmental noise and effects on annoyance. The equation is as follows $\%HA = (78.9270 - (3.1162 \times Lden) + (0.0342 \times Lden^2))$. This quadratic regression equation is highly significant ($P<0.001$) with an R square of 0.325 at 95% confidence (Gusku et al., 2017). The equation to find the population highly sleep disturbed by traffic noise is from the study by Basner and MvGuire (2018), The equation is as follows $\%HSD = (19.4312-(0.9336 \times Lnight) + (0.0126 \times Lnight^2))$. This exposure response equation is recommended in the WHO 2018 Environmental Noise Guidelines for the European Region and was used in this study. The final step is to apply a disability weight which are weighting factors for the severity of diseases on a scale from 0 to 1. Zero is representing a status of full health whereas one is understood as a state comparable with death (Devleesschauwer, 2014). The disability weight is applied to the number of people that are highly annoyed and the number of people that are highly sleep disturbed due to traffic noise resulting in the final DALYs number. The Disability weight for Annoyance is 0.02 and Sleep disturbance is 0.07.

3.5 Mapping

ArcMap 10.71 (ESRI, Redlands, CA, USA) was used to visualize the data results spatially across Toronto. The Toronto dissemination area boundary file from 2016 was downloaded from Statistics Canada to complete the mapping. The total DALYs from each health outcome were aggregated into dissemination areas in order to observe where in the city of Toronto the DALYS are being experienced as a total and for each health outcome separately. Additionally, the average decibel levels for Lden and Lnight were mapped at a dissemination area level to help understand where the highest average noise was experienced during the day and nighttime hours. Choropleth maps were used to visualize with a graduated color scale to show the data in a way that highlights the most problematic areas with the most intense color and the less problematic areas with a softer less prominent hue.

4.0 Results

This chapter will present the results from each health outcome being incorporated into the Toronto burden of disease due to traffic noise study which includes, Ischemic Heart Disease, annoyance, and sleep disturbance. The mapping results will be presented, and a brief analysis of the spatial findings will be discussed. Noise pollution in Toronto is experienced by everyone, however there are thresholds for which major health concerns start to arise. Table 1 provides an overview from the Toronto noise data taken from the study by Oiamo et al, 2018. For the average day time noise levels (Lden) the Min and Max are higher than that of nighttime levels (Lnight) as expected. The average noise levels in Toronto during the day are 16dB louder than at night. The range of decibel levels shown in Table 2 is based on a synthesized collection of studies from the World Health Organization where the corresponding health outcomes have been statistically significant to occur using the exposure response functions.

4.1 Traffic Noise Levels in Toronto

The health outcome decibel ranges seen in Table 2 are referenced as follows, IHD: 53dB - 80dB (Van Kemper et al., 2018), Annoyance: 45dB - 80dB (Guski et al., 2017), and Sleep Disturbance: 40dB - 65dB (Basner & McGuire, 2018). It is important to understand that these ranges are to make sure the exposure response functions hold statistically significant. Table 2 also highlights the number of people and percent of the total Toronto population is exposed to the noise levels that are known to cause the health outcomes studied. 90.8% of Toronto's population is exposed to daytime (Lden) levels that can cause Ischemic Heart Disease, 96.3% are exposed to levels which can cause high levels of annoyance, and 98.1% of Toronto's population experiences night time (Lnight) noise levels that have been seen to cause high levels of sleep disturbance. The results will be discussed for each health outcome in the following section.

Table 1: Toronto dB Levels in 2018

Summary Statistics	Lden	Lnight
Min	45db	35db
Mean	72db	57db
Max	99db	79db

Table 2: Toronto Noise Thresholds and Exposure in 2018

Health Outcome	Decibel Threshold	Number of People Exposed	% of Population
IHD	Lden 53dB - 80dB	2,505,187	90.8%
Annoyance	Lden 45dB - 80dB	2,656,098	96.3%
Sleep Disturbance	Lnight 40dB - 65dB	2,704,875	98.1%

The number of people exposed at each individual decibel level is shown below in Table 3 for (Lden) and Table 4 For (Lnight). Table 1 clearly shows there are people being exposed to noise at much lower and much higher decibel levels outside the given ranges, and one could assume noise louder than the higher end of the IHD, annoyance, and sleep disturbance for would only cause more overall health issues. In order to include the population that experiences dB levels above the exposure response constraints, those that were above the top end were treated as if they only experienced the max level of dB within the threshold. As explained in the methods section, the exposure response equation incorporates risk; each dB level increase causes an increase risk to causing a health outcome, this risk was capped at the top end dB of the threshold for each health outcome This was done to make sure there was not a large amount of the Toronto population being omitted from the study. Shown in Table 3 there are 355,198 people that experienced higher than 80dB of daytime noise (Lden) and in Table 4, 88,545 people experienced higher than 65dB of nighttime noise (Lnight).

Table 3: (Lden) Population Exposure at each dB Level in Toronto 2018

Lden (dB)	# of People Exposed	% of Exposed Population	Lden (dB)	# of People Exposed	% of Exposed Population
45	1,783	0.07%	**73**	61,871	2.33%
46	3,021	0.11%	**74**	58,559	2.20%
47	6,530	0.25%	**75**	65,960	2.48%
48	13,934	0.52%	**76**	74,044	2.79%
49	15,263	0.57%	**77**	26,062	0.98%
50	19,990	0.75%	**78**	79,216	2.98%
51	38,317	1.44%	**79**	68,284	2.57%
52	52,073	1.96%	**80**	80,709	3.04%
53	60,317	2.27%	**81**	66,832	2.52%
54	61,655	2.32%	**82**	69,382	2.61%
55	69,587	2.62%	**83**	58,603	2.21%
56	70,080	2.64%	**84**	13,479	0.51%
57	81,227	3.06%	**85**	37,343	1.41%
58	100,304	3.78%	**86**	30,628	1.15%
59	125,715	4.73%	**87**	8,858	0.33%
60	124,684	4.69%	**88**	8,303	0.31%
61	115,936	4.36%	**89**	7,308	0.28%
62	115,789	4.36%	**90**	8,537	0.32%
63	86,594	3.26%	**91**	5,365	0.20%
64	97,285	3.66%	**92**	3,379	0.13%
65	90,377	3.40%	**93**	2,948	0.11%
66	73,752	2.78%	**94**	4,014	0.15%
67	78,938	2.97%	**95**	3,454	0.13%
68	64,732	2.44%	**96**	4,614	0.17%
69	72,900	2.74%	**97**	1,662	0.06%
70	44,892	1.69%	**98**	471	0.02%
71	59,419	2.24%	**99**	18	0.00%
72	61,101	2.30%	**Total**	2,656,098	100.00%

Table 4: (Lnight) Population Exposure at each dB Level in Toronto 2018

Lnight (dB)	# of People Exposed	% of Exposed Population	Lnight (dB)	# of People Exposed	% of Exposed Population
40	37,673	1.39%	**61**	95,213	3.52%
41	63,872	2.36%	**62**	88,918	3.29%
42	104,921	3.88%	**63**	67,737	2.50%
43	144,083	5.33%	**64**	51,642	1.91%
44	178,971	6.62%	**65**	35,746	1.32%
45	223,067	8.25%	**66**	18,327	0.68%
46	206,825	7.65%	**67**	13,365	0.49%
47	154,426	5.71%	**68**	8,283	0.31%
48	131,375	4.86%	**69**	6,865	0.25%
49	116,849	4.32%	**70**	9,807	0.36%
50	98,474	3.64%	**71**	7,404	0.27%
51	87,262	3.23%	**72**	4,969	0.18%
52	80,461	2.97%	**73**	7,154	0.26%
53	74,011	2.74%	**74**	4,451	0.16%
54	73,527	2.72%	**75**	4,660	0.17%
55	74,860	2.77%	**76**	2,345	0.09%
56	71,182	2.63%	**77**	684	0.03%
57	86,928	3.21%	**78**	18	0.00%
58	84,322	3.12%	**79**	213	0.01%
59	94,832	3.51%	**-**	-	-
60	89,153	3.30%	**Total**	2,704,875	100.00%

4.2 Ischemic Heart Disease Results

This report seeks to attribute these health outcomes as a result of traffic noise and to then quantify the effects in terms of burden of disease measured in Disability Adjusted Life Years (DALYs). The first health outcome calculated was Ischemic Heart Disease. As explained earlier the Canadian Global Burden of Disease for Ischemic Heart Disease from the Institute of Health Metrics and Evaluation database (IHME, 2017) was used as proxy to infer the IHD results in Toronto. The 2017 Canadian population was 36,543,300 and Toronto population was 2,757,932 taken from (Statistics Canada, 2017) which is the year the IHD data was taken from for this study.

Seen in Table 5 below, the 2017 Canadian burden of disease DALYs results from Ischemic Heart Disease are totaled at 661,098. This means that in 2017 Canadians lost 30,894 healthy years lost due to having IHD and 630,204 years of life lost due to premature death as a result of IHD. The ratio of Toronto's population to Canada's as a whole was found and the Toronto estimates were calculated. In 2017 Toronto lost 2332 healthy years to IHD and 47,562 years lost due to premature death from IHD. In order to calculate how many of these DALYs can be attributed to traffic noise specifically, the Population Attributable Fraction (PAF) had to be calculated as shown in Table 6. The relative risk for someone getting IHD due to traffic noise was derived in the World Health Organization Noise Study by (Van Kemper et al., 2018) The relative risk for every 10dB above 53dB is 1.08%. The 2018 Toronto traffic noise data was used to calculate this risk at each decibel level and the 2017 IHD levels derived for Toronto will be assumed to stay similar in 2018, as there was no update to the database for 2018. The final PAF was found to be 9.86%. This means that for every DALY that was due to IHD in 2018 in Toronto, 9.86% of them can be attributed to traffic noise levels in Toronto. The results show that 230 healthy years were lost to traffic noise induced IHD and 4,690 years were lost due to premature death caused by traffic noise induced IHD.

Table 5: IHD DALYs Calculation Roadmap for Toronto 2018

2017 Canadian Global Burden of Disease (GBD) Metrics	2017 Canadian GBD due to IHD	Ratio of Toronto Population to Canadian Population	Toronto Estimates Based on 2017 Canadian GBD Data	Population Attributable Factor (Traffic Noise)	2017 Toronto Estimates Burden of Disease due to IHD Attributable to Traffic Noise
Death	48,381	0.075	3,651	Not applicable	Not applicable
YLD	30,894	0.075	2,332	9.86%	230
YLL	630,204	0.075	47,562	9.86%	4,690
DALY	661,098	0.075	49,893	9.86%	4,920

Table 6: Population Attributable Fraction Roadmap

Relative Risk of Traffic Noise Causing IHD	Equation to Calculate Relative Risk at Each dB Level	Population Attributable Fraction (PAF)
Every 10dB Increase past Lden 53dB = 1.08% risk	EXP((LN(1.08)÷10) x (Lden - 53))	9.86%

4.3 Annoyance Results

Seen in Table 7, the total number of people exposed to daytime noise levels between 45dB and 60 dB was 2,656,098 people in Toronto. The exposure response equation is shown below which provides the total number of people reported to have been “highly annoyed” by the noise which is caused by traffic (665,559 people). In 2018, 24% of the Toronto population was “highly annoyed” by daytime traffic noise. The disability weight of (0.02) is used to convert the idea of being “highly annoyed” into a morbidity scale and provides the result for DALYs equaling 13,311. This means that 13,311 healthy years were lost due to traffic noise causing people a high level of annoyance during the day in Toronto in 2018.

Table 7: 2018 Toronto Annoyance DALYs Results

# of People Exposed at 45dB - 80dB	Exposure Response Equation	# of People Highly Annoyed due to Traffic Noise	% of Total Population Highly Annoyed Due to Traffic Noise	Disability Weight (DW)	DALYs Due to Traffic Noise
2,656,098	(78.927-(3.1162 x Lden)+(0.034 x Lden^2))	665,559	24%	0.02	13,311

4.4 Sleep Disturbance Results

Seen in Table 8, the total number of people exposed to noise levels between 40dB and 65dB at night was 2,704,875 people in Toronto. The exposure response equation is shown below which provides the total number of people reported to have been "highly sleep disturbed" by the noise which is caused by traffic (144,976 people). In 2018, 5% of the Toronto population was "highly sleep disturbed" by nighttime traffic noise. The disability weight of (0.07) is used to convert the idea of being "highly sleep disturbed" into a morbidity scale and provides the result for DALYs equaling 10,148. This means that 10,148 healthy years were lost due to traffic noise causing people a high level of sleep disturbance at night annually.

Table 8: 2018 Toronto Sleep Disturbance DALYs Results

# of People Exposed at 40dB - 65dB	Exposure Response Equation	# of People Highly Sleep Disturbed	% of Total Population Highly Sleep Disturbed Due to Traffic Noise	Disability Weight (DW)	DALYs Due to Traffic Noise
2,704,875	(19.4312-(0.9336 x Lnight)+(0.0126 x Lnight^2))	144,976	5%	0.07	10,148

4.5 Overall DALYs

The overall results for DALYs can be seen in Table 9 below. The total Disability Adjusted Life Years in Toronto in 2018 due to traffic noise causing Ischemic Heart Disease, high levels of annoyance, and high levels of sleep disturbance was 28,380 years. Ischemic heart disease is the only health outcome that can directly be linked to (YLL) years of life lost as it causes mortality, however the years of life lived with a disability (YLD) in terms of morbidity showed the largest contribution to the DALYs. Annoyance contributed the most at 47% of the DALYs, Sleep Disturbance contributed 36% of the DALYs and Ischemic heart disease contributed 17% to the total resulting DALYs for Toronto in 2018. The DALYs per 100,000 people exposed is listed as this makes it possible to compare the results to different studies of varying sizes.

Table 9: 2018 Overall Toronto DALYs Results

Health Outcome	YLL	YLD	DALYs	DALYs Per 100,000 Exposed
IHD	4,690	230	4,920	196
Annoyance	0	13,311	13,311	501
Sleep Disturbance	0	10,148	10,148	375
Total	4,690	23,689	28,380	1,073

4.6 Choropleth Maps

As noise pollution is a public health issue that affects everyone across Toronto, being able to spatially analyze where noise pollution is most prominent and least prominent adds an extremely helpful layer to tackling the issue. By utilizing GIS in this study, the average dB levels for daytime and nighttime were aggregated into dissemination areas across Toronto to take a look at which areas show certain levels of noise pollution.

Figure 2 showcases the (Lden) daytime decibel levels across Toronto. The areas that see the darkest red color are those which are experiencing average daytime noise levels of 81dB - 90dB. These areas are generally found along the major highways such as highway 401 (east/west along the middle), the Don Valley Parkway (Running north/south in the middle), the Gardiner Expressway (running east/west along the bottom), and Highway 427 (running north/south on the left side). Some of the other highlights would be the downtown core of Toronto which shows generally daytime noise levels from 71dB – 80dB and in some areas 81 – 90dB). Seen in Figure 3 is the same map except with the average nighttime (Lnight) noise levels. There is a very similar pattern with the highways experiencing the majority of the high decibel levels, however at night these areas experience a much higher level of noise compared to the surrounding dissemination areas. This means that these areas stay quite loud during the day and night as they are the major highways for traffic at any time of day.

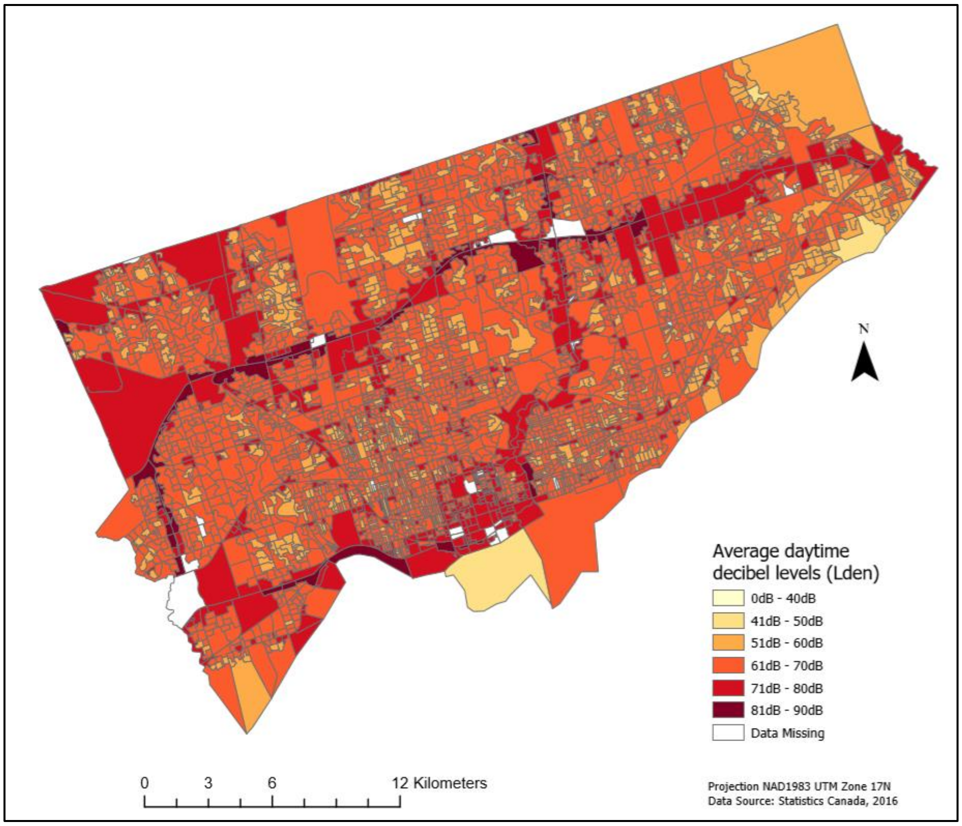

Figure 2: Average Daytime Decibel Levels by Dissemination Area in Toronto, 2018

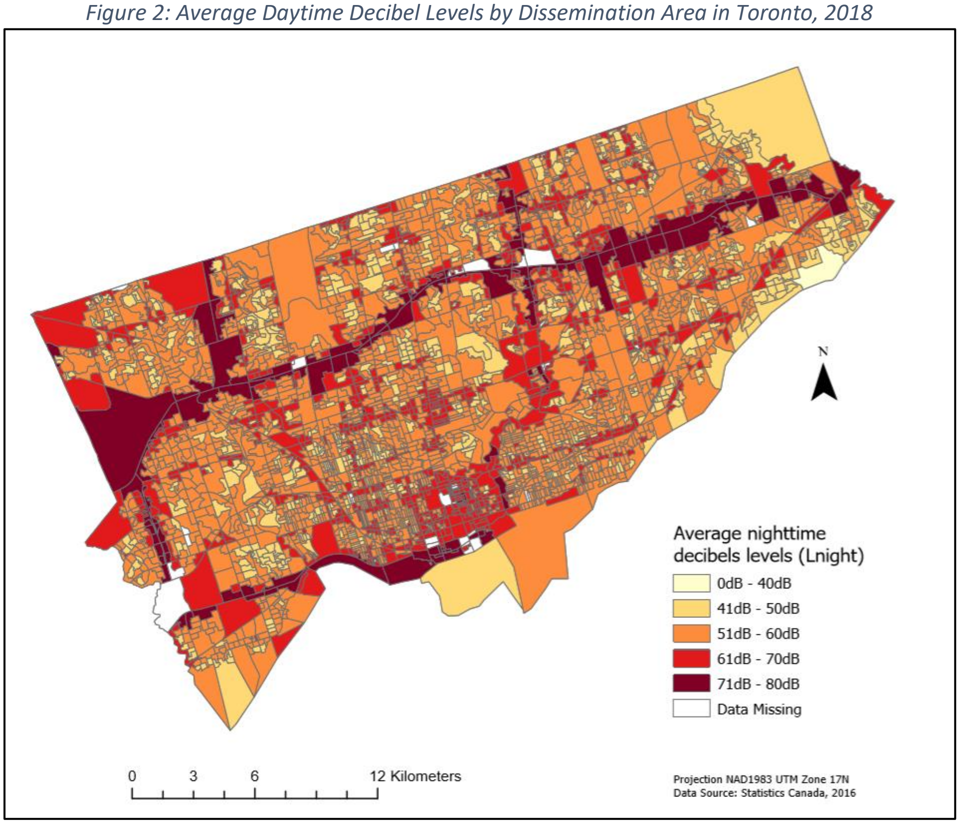

Figure 3: Average Nighttime Decibel Levels by Dissemination Area in Toronto, 2018

In Figure 4 the DALYs associated with Ischemic Heart Disease as a result of traffic noise was aggregated and mapped by dissemination areas in Toronto. There seems to be a random dispersion of where DALYs are higher, however in the downtown core there seems to be the largest concentration of high numbers of DALYs in the 21-50 years range.

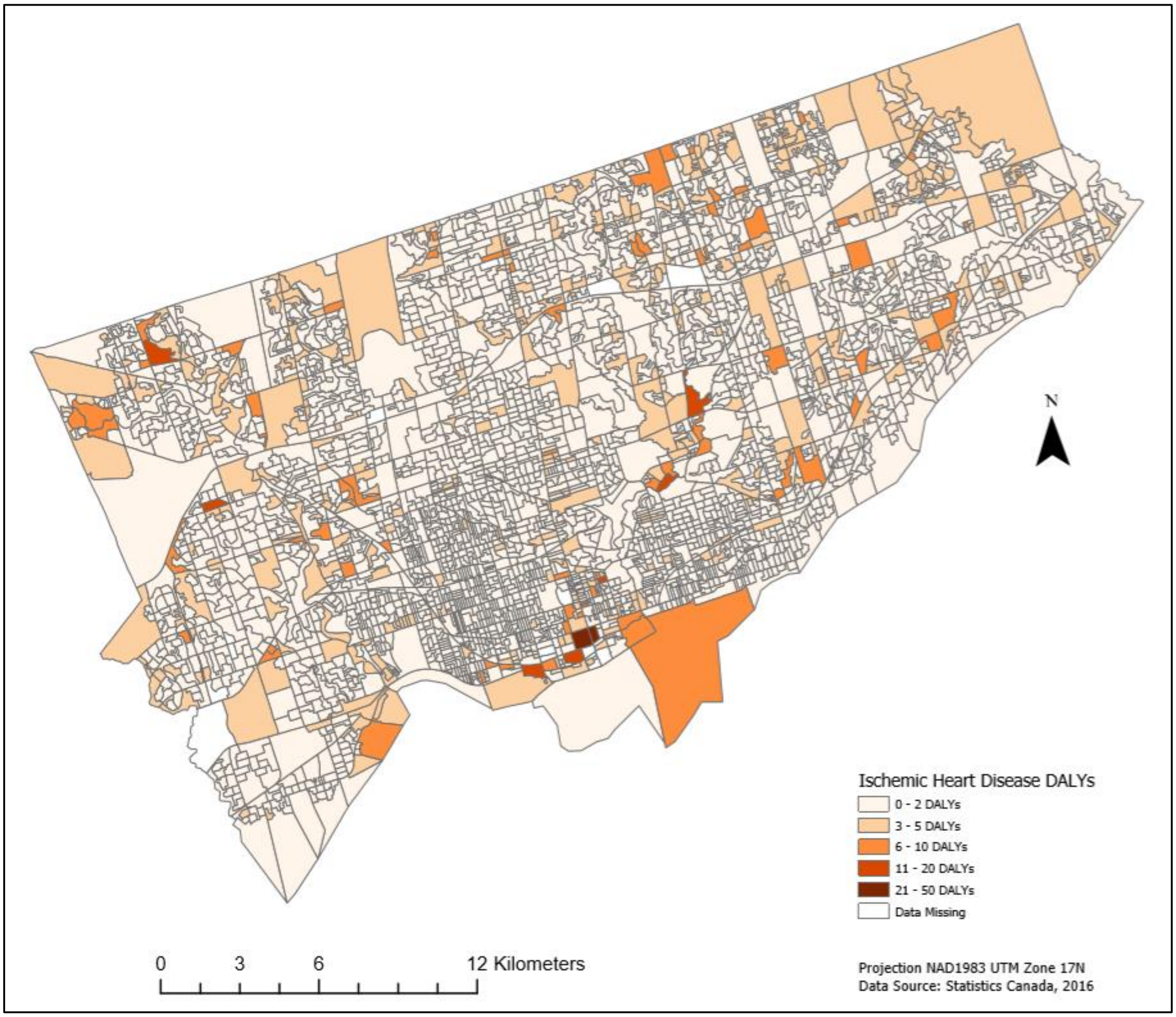

Figure 4: Ischemic Heart Disease DALYs due to Traffic Noise Exposure by Dissemination Area in Toronto, 2018

Figure 5 showcases the DALYs from traffic noise causing high levels of annoyance. The problem areas seem to follow a bit of a linear pattern along the highway routes where the highest levels of noise are seen during the daytime and nighttime hours. The downtown core has the largest cluster of DALYs with the highest range of 11 – 30 DALYs and 31-70 DALYs in a single Dissemination area. This can be expected as there are a large number of people living in the downtown core and the core experiences high levels of noise throughout the day.

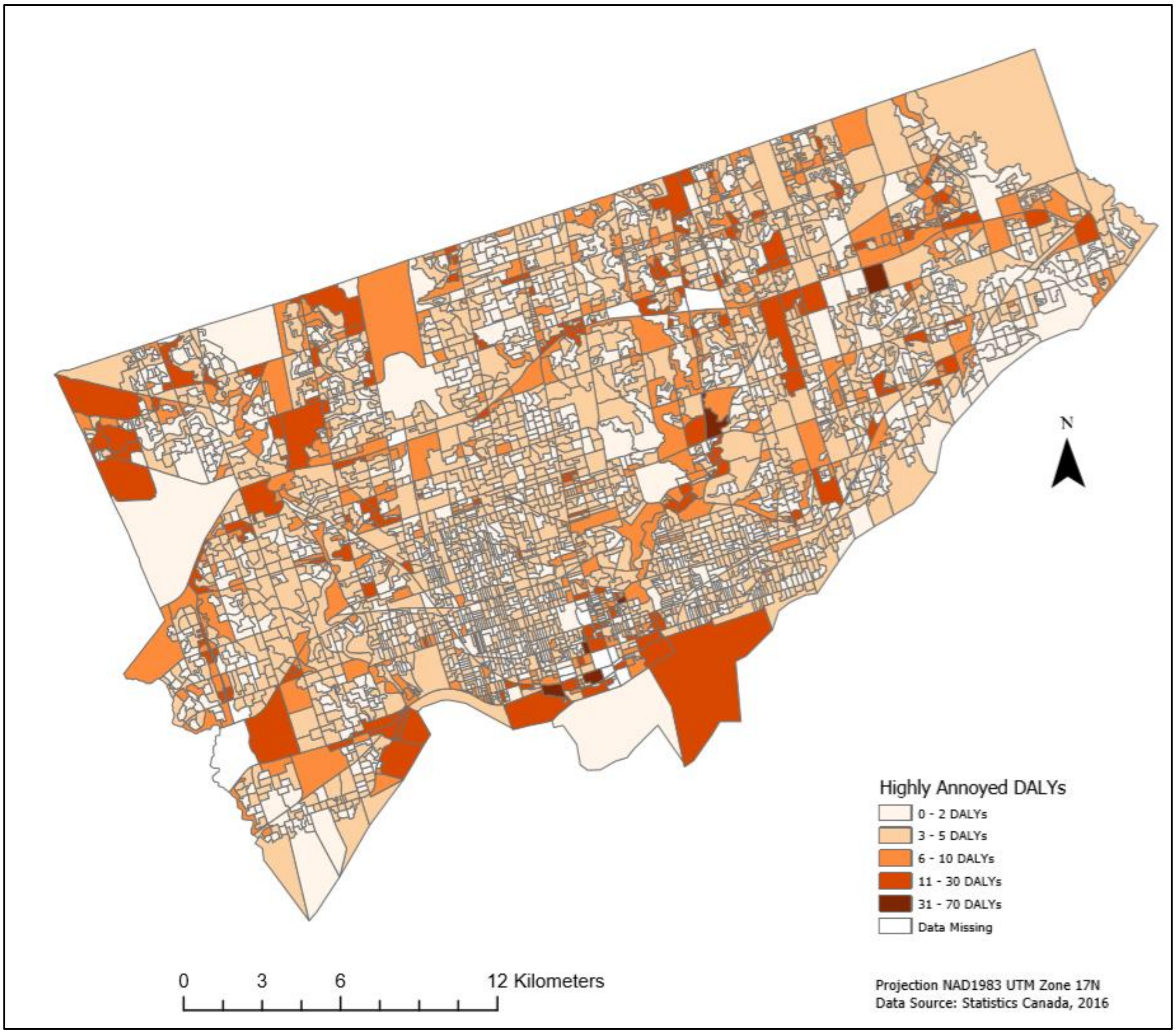

Figure 5: Highly Annoyed DALYs due to Traffic Noise Exposure by Dissemination Area in Toronto, 2018

Sleep disturbance seen in Figure 6 shows the most random dispersion of DALYs among the Toronto Dissemination areas. There is one dissemination area that sees extremely high DALYs but upon further analysis, found out that this area borders a park where the Canadian Pacific Railway crosses a bridge parallel to Dundas Street crossing a bridge, it is likely that noise readings in this area could have been overestimated as a result of the unobstructed train noise.

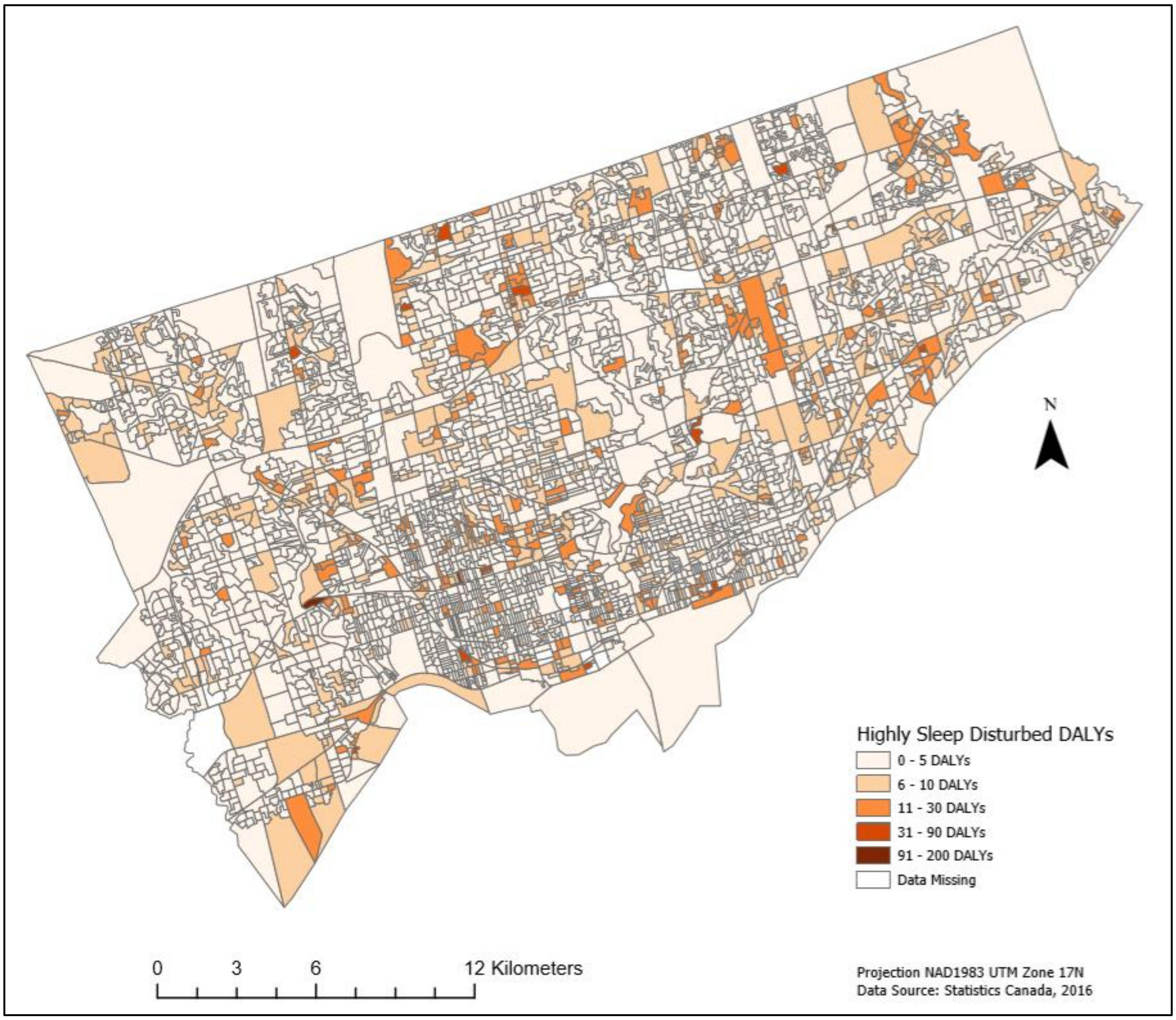

Figure 6: Highly Sleep Disturbed DALYs due to Traffic Noise Exposure by Dissemination Area in Toronto, 2018

The final map, shown in Figure 7, is a combination of all the DALYs due to traffic noise from the three health outcomes explored IHD, Annoyance, and Sleep Disturbance. The problem areas span across most of the city, however there is a cluster in the core that then trails alongside the Canadian Pacific Railway that is likely contributing to the traffic noise readings. The majority of the overall DALYs are as expected around major traffic highways which coincide with many of the train routes through Toronto as well.

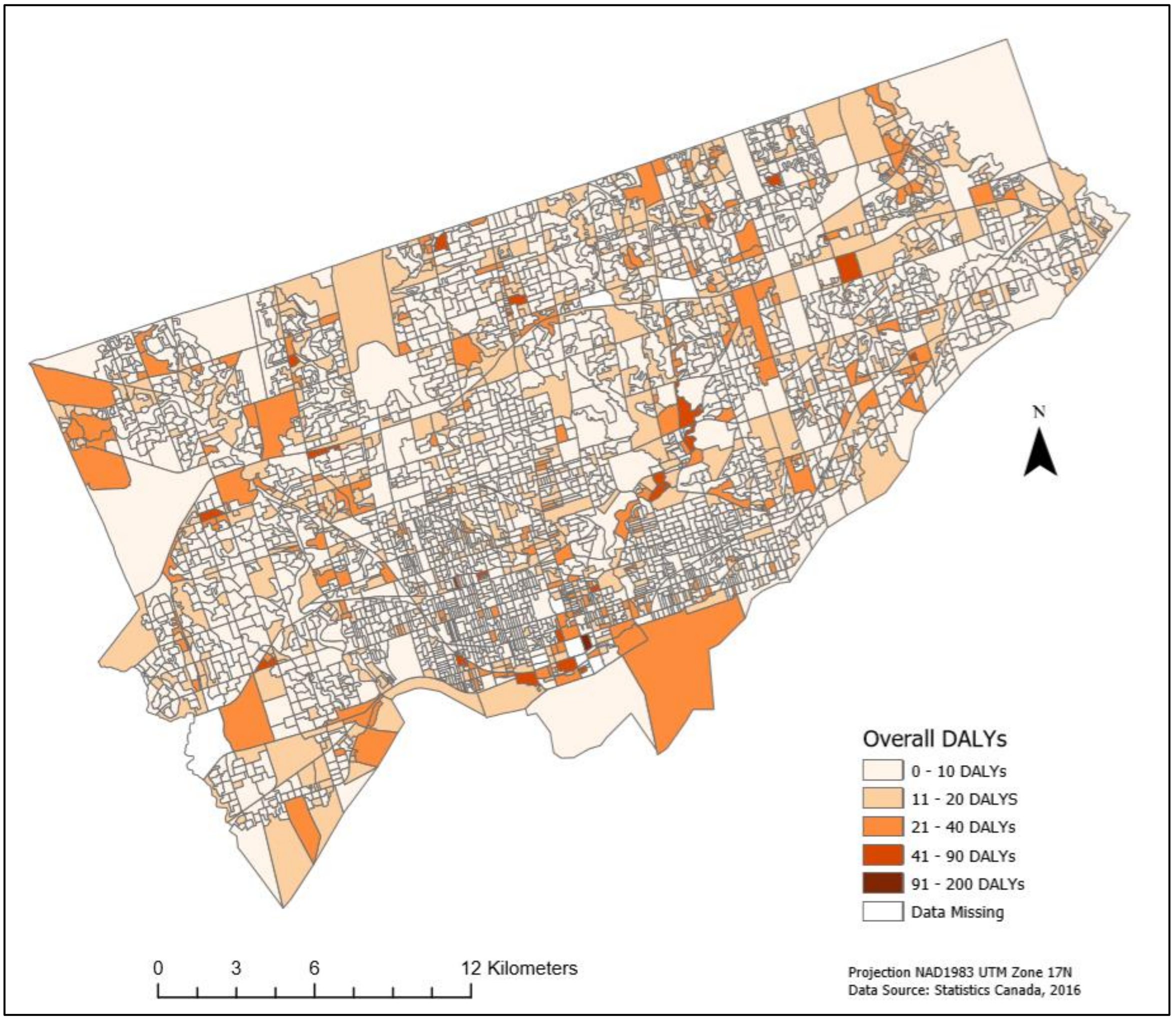

Figure 7:Overall DALYs due to Traffic Noise Exposure by Dissemination Area in Toronto, 2018

5.0 Discussion & Conclusion

This section will provide a comparison study to showcase how utilizing DALYs as a metric can provide valuable comparative ability between various study areas that range in size and location. A discussion on limitations and considerations found in this study will be explained and finally some concluding statements about the project and future application will be mentioned

5.1 Comparison Study

Disability Adjusted Life Years (DALYs) is a measurement that has been used to try and quantify and give meaning and comparability to the overall effects that certain pollutants can cause to public health. A similar study to this was conducted in Germany titled, "Burden of Disease Due to Traffic Noise in Germany" (Tobollik, 2019) which looked at noise pollution from traffic, rail, and air sources and how they can cause the same three health outcomes, IHD, annoyance, and sleep disturbance. The resulting DALYs found for each health outcome per 100,000 people exposed to noise levels that can cause each health outcome was compared between Germany and Toronto. Overall Toronto had more DALYs due to traffic noise affecting their citizens (1,073 DALYs/100,000) compared to Germany (952 DALYs/100,000). Toronto had higher rates of traffic noise induced IHD (196 DALYs/100,000) and Annoyance (501 DALYs/100,000). However, Germany suffered from higher DALYs due to Sleep Disturbance (454 DALYs/100,00). These results could mean the on average Torontonians are exposed to higher levels of noise and thus experience more effects from traffic noise. Toronto being a smaller study area and Germany being a much larger study area, the average noise is likely higher in the dense urban setting of Toronto than the country of Germany as whole. Germany does seem to experience higher DALYs for sleep disturbance which could mean there is a higher sensitivity to noise or potentially infrastructure is not as soundproof for when people are sleeping.

5.2 Considerations

Although (Lden) and (Lnight), which are A-weighted equivalent continuous sound pressure levels during a time interval, from the ISO 1996-1:2016 standards, it is important to note that there are many other noise metrics available that involved in noise studies. For example, C-weighting, which is a frequency-dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies and is generally used for peak measurements. Leq.8h is a metric that corrects for the length of the working shift, in one case it could be 8h (World Health Organization, 2018).

It is important to note that due to a lack of local studies and data around noise and access to individual level Ischemic heart disease to calculate DALYs, Canadas country level burden of disease study was used as representative data for Toronto. There are many factors that feed into the relative rates of IHD, including access to healthcare, socio-economic factors, size and density of the population, and in this study in particular, the levels of environmental noise pollution that could feed into IHD rates. Using Canada as representative of Toronto may lead to over or under estimations on the rates of IHD. An argument for an under estimation of DALYs could be made when only considering noise pollution as a factor. Toronto is much more densely developed with more buildings and road networks than any other city in Canada and overall noise levels is likely much higher than other regions of Canada. On the flip side, when taking into account the multitude of factors that actually feeds into rates of IHD, Toronto may actually be overestimated by using Canada as representative IHD DALYs rates. Representative data is what was available at the time of this study and so this has to be accepted as a limitation in the data.

The use of exposure response equations from the World Health Organizations Noise guidelines for the European region were utilized to estimate DALYs from annoyance and sleep disturbance. These equations take a synthesis of many studies primarily done in Europe to provide an estimate of people's responses to different levels of noise. As there is a lack of firsthand studies in Toronto and North America overall, these are the best models available at the time of this study. It is possible that European studies could cause an over or under estimation due to the fact that people in Europe may be more or less sensitive to noise, and the general infrastructure and urban designs may cause more or less potential for noise to be exposed to its citizens.

Another is a possible over or under estimation could come from overlap between different outcomes, where, e.g., a person who feels annoyed by noise also might have or develop ischemic heart disease. The cumulative effects of the exposure to various noise sources at the same time are complex. There is an ongoing scientific discussion about the best way to model combined noise exposure and how to assess the combined health effects (Tobollik et al., 2019) however for this study this factor was not considered.

There have been many studies that show there are strong relationships between sleep disturbance and cardiovascular problems such as ischemic heart disease. It is true that there is likely some overlap in counting when measuring the DALYs. The reasoning for including both is that although there may be some overlap, there are plenty of growing studies regarding other health issues that are being affected due to sleep disturbance as well as from noise exposure in general. Without these additional health outcomes having enough research to be included, it can also be said that there is a potential for under counting

DALYs as a result of omitting certain known health outcomes due to noise. As this is a growing area of study, it must be noted that results are an estimation based on best practices and guidelines at the time of conducting the research.

When aggregating noise decibels into the dissemination areas for mapping the results in Toronto, the data could show over and under estimation due to the dB getting averaged and populations within the dissemination areas are confined to that average decibel level. Likely due to the larger upper range of dB the overall DALYs are an overestimation on the maps however they provide an insightful way to visualize where the effects of noise is in the city and where problem areas may exist.

5.3 Conclusion

It is important to remember that noise pollution can cause more health outcomes than just the three outlined in this study. As explained in the literature review, there are studies suggesting there are links to cognitive impairment, adverse birth outcomes, mental health, type 2 diabetes, and obesity, but the data is not concrete yet (World Health Organization, 2018). In addition to this, this study was only looking at traffic noise specifically as a contributor to dB levels and health outcomes; other major sources of noise such as trains, airplanes, major construction, infrastructure services such as HVAC, and even wind turbines are components to most major urban areas and are all adding to the noise pollution problem (World Health Organization, 2018).

Many of the health outcomes mentioned are not only bad for public health, but it means there will be a large cost on public services and government spending in general. An increase in hospital visits due to cardiovascular problems, more emergency vehicles dispatched for heart attacks, more drug prescriptions to treat cardiovascular or even sleep problems. Those who find themselves highly sleep disturbed consistently may also develop other health problems and become less productive at work. If noise becomes a consistent annoyance, irritability and overall happiness can be affected, leading to potentially more mental health problems. These echoing costs must also be accounted for when considering the severity of this public health issue.

Based on the results of mapping the noise decibel data and comparing it to the areas where the highest DALYs were experienced, the common trend was that the major highways were nearby the areas that experienced the highest number of healthy years of life lost. This should be a strong indication that current noise dampening measures, such as the walls bordering neighbourhoods that situate right beside these major transport routes, are not working to reduce harmful levels of noise. Better dampening solutions must be developed to keep those who live nearby the major highways safe from harmful levels of noise exposure.

Europe has set the stage for best practices to collect and monitor noise pollution from a variety of sources as seen in the, "World Health Organization Environmental Noise Guideline for the European Region 2018" and the "Environmental Noise Directive 2002/49/EC". These methods and equations have been borrowed and applied to this North American scenario in Toronto, however more studies need to be carried out in North America in order to have the most accurate results and understanding of how noise affects urban areas on this side of the world.

There is enough evidence to show that noise pollution is a public health issue and is affecting human health in known and unknown ways. As our cities grow and more of the population is exposed to high levels of noise, there needs to be an understanding and a strategy to help mitigate and limit them so the safety of public health. This study aimed to bring attention to the problem of noise pollution by utilizing local scale noise data and applying methods from the World Health Organizations Burden of Disease Studies for Noise Pollution to explain and present the importance of this issue. Having local or regional data available for Ischemic Heart Disease, as well as firsthand data on people's experiences with noise as it pertains to annoyance and sleep disturbance would make studies like this one much more powerful and informative. Having knowledge of what levels of noise can cause health problems and spatially know where it is happening by using GIS can help law makers, city planners, and public health administrators to effectively address these problems.

As this is one of the first studies in North America to quantify noise pollution into a measurable and comparable metric as it pertains to health outcomes in the form of Disability Adjusted Life Years, it should act as an example and starting point for future studies. There are already many studies using the same metric to measure global burden of disease (DALYs) for other environmental factors such as air quality, however as environmental noise pollution is the second largest environmental health issue facing public health in Europe, it is likely the same for North America. It is vital that studies like this are taken seriously and are used to help push policy makers and government officials to make environmental noise pollution a priority to public health. Hopefully we will see an Environmental Noise Guidelines for the North American Region in the future.

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