Chapter 1

Introduction

1.1 General

The urbanization of the planet is the most tangible manifestation of the changes in global human settlement patterns. Rapid urbanization is occurring in many regions globally. In 1800, a mere 2 percent of the world's population resided in urban areas. By 1900, this figure had increased to just 15 percent. However, the 20th century saw a dramatic transformation in this trend, with urban population growth accelerating significantly from the 1950s onward [1]. Urbanization has had a profound impact on road transport, leading to various improvements i.e. enhanced road transport, increased accessibility, development of traffic management system, growth of public transport and economic benefits etc. but it has some negative side also for e.g. it has caused a significant increase in vehicle numbers, straining road capacity and efficiency in urban areas, congestion and a surge in private vehicle ownership. Apart from these negative sides; there is urgent need to look pollution emerging from vehicles i.e. air pollution and noise pollution. Environmental pollution comes in two forms - air pollution and noise pollution. Much research has been carried out to reduce air pollution, but noise pollution has been overlooked in most developing economies. Due to the steady population growth and the rapid growth in traffic, traffic-induced pollution has reached significantly high levels. Road traffic noise is a pressing issue in contemporary times, impacting individuals in various ways. It is crucial to emphasize the importance of addressing this problem seriously.

1.2 Noise Pollution

Noise is defined as unwanted or harmful sound, often noted for being unpleasantly loud, causing a disturbance in communication and speech clarity, and disrupting activities such as sleep and mental focus, potentially posing a risk to one's hearing. Any undesired disruption occurring within a useful frequency range is termed as 'noise'. From a physics perspective, there is no inherent differentiation between noise and desired sound, as both manifest as vibrations through a medium, such as air or water. The contrast emerges when the brain processes and interprets the received sound signals.

The World Health Organisation (WHO) has been addressing the issue of noise pollution in communities since 1980. Environmental noise, residential or domestic, can be called community noise and originates from all sources except for noise generated in industrial workplace [2]. Among the primary environmental hazards to health and welfare is environmental noise. Environmental noise refers to any undesirable and detrimental outside noise produced by human activity, such as industrial and transportation (such as air, rail, and road traffic) [3]. People residing in urban areas often express their dissatisfaction with the level of noise pollution. The most common complaints about noise in cities and their environs come from traffic, then from nearby homes and businesses, and finally from aircraft [4]. Among the many environmental factors that can have a negative impact on human health in Western Europe, transport noise ranks second only to particulate matter in terms of severity [5]. Numerous studies have demonstrated the detrimental effects of traffic noise on human health.

Noise is measured in decibels (dB) using the A-weighting scale, which reflects the frequency range of human hearing (20 Hz to 20 kHz). The term L_{eq} (Equivalent Continuous Noise Level), is a commonly used noise descriptor in research and environmental studies [6, 7]. It represents the continuous equivalent level of fluctuating noise over a specified period, providing a single value that reflects the overall noise energy. The Equation (1.1) representing L_{eq} is shown below.

$$L_{eq} = 10 \log[\frac{1}{t_2 - t_1} \int_{t_2}^{t_1} p^2(t)/p_r^2]dt \quad (1.1)$$

Where $P(t)$ = time varying sound pressure level, p_r = reference pressure, $t_1$and t_2 are limits of time under consideration.

A pivotal document linking noise and public health concerns was produced by the World Health Organization (WHO) titled "Guidelines for Community Noise [2]. This document was ground-breaking in establishing noise pollution as a significant public health issue globally. The WHO found that around 40% of the European Union (EU) population was exposed to noise level exceeding 55 dB(A) during day and around 30% during night. When considering all transportation-related noise, approximately 50% of EU citizens were found to live in areas of acoustical discomfort. In response to the increasing evidence, the European Community's 6th Environmental Action Programme specifically addressed the issue of environmental noise. In India, the Central Pollution Control Board (CPCB) adheres to the WHO guidelines for noise level limits. The WHO noise quality guidelines provide summarized values tailored to specific environments and their effects. WHO guidelines for noise as per [2] is provided in Table 1.1. Time base is the duration involved for monitoring of sound level for day or night time which is sustainable for comfortable living with their respective range of sound level. Time Base for L_{Aeq} for day time and night time is 12-16 hour and 8 hours respectively. No time base is given for evenings, but typically the guideline value should be 5-10 dB lower than the day time. Other time bases are recommended for schools, pre-schools and playground depending on activity.

Table 1.1. WHO guidelines for noise

Specific Environment	**Time Base (hours)**	**Standard limits as per WHO guidelines**	
		L_{Aeq} **[dB]**	L_{Amax}, ***fast*** **[dB]**
Outdoor living area	16	50 - 55	-
Dwelling, indoors, Inside bedrooms	16 8	35 30	- 45
Outside bedrooms	8	45	60
School class rooms and pre-schools, indoors	During class	35	-
Pre-school bedrooms, indoors	Sleeping time	30	45
School, playground outdoor	During play	55	-
Hospital, ward rooms, indoors	8 16	30 30	40 -
Hospitals, treatment rooms, indoors	-	As low as possible	-
Industrial, commercial, shopping and traffic areas, indoors and outdoors	24	70	110

1.3 Impact of Traffic Noise on Health

Road traffic noise is recognized as a public health risk by the WHO. It mentions that exposure to noise levels higher than 55 decibels (dB(A)) should be avoided for the associated health risks [8]. The World Health Organization's European Centre for Environment and Health in Bonn developed a guidance document for quantitatively assessing the health risks associated with environmental noise [9]. The health effects considered were annoyance, sleep disturbance, cognitive impairment, cardiovascular disease. Many literatures also listed effects include hearing loss, insomnia, cardiovascular complications, metabolic disease, annoyance, speech interference, infertility, cognitive impairment, poor mental health, and overall bad well-being [10-15]. Environmental noise poses a significant public health burden in Europe. Chronic exposure contributes to approximately 48,000 new cases of heart disease and 12,000 premature deaths annually. Additionally, noise pollution adversely affects quality of life, with 22 million individuals experiencing persistent high levels of annoyance and 6.5 million suffering from chronic sleep disturbances [16]. Noise pollution significantly impacts public health, resulting in the loss of one million healthy life years annually. This is primarily attributed to annoyance, sleep disturbances, and ischemic heart disease. Annoyance and sleep disruption are the most prevalent health burdens associated with noise exposure [16]. Noise annoyance is strongly linked to increased mental stress and a higher risk of developing mental health conditions like depression and anxiety [17]. The WHO regional office for Europe revised their guidelines on environmental noise in 2018 in response to mounting evidence of the burden of noise-related diseases [18] [19]. In Europe, Swedish legislation mandates noise levels at new building façades to be below $L_{\mathrm{Aeq,24h}}$ of 60 dB(A) [20] or L_{den} of 63 dB(A).

Approximately 10 dB(A) gap occurs between Swedish legislation and WHO health-based guidelines.

1.4 Traffic Noise Pollution in Mid-Size Indian City

According to many literature; mid-sized cities are defined as those with populations ranging from 0.5 to 5 million [21, 22] [23] [24]. According to the Census of India 2011 [25] the cities in India were divided in three broad categories a) Class I Towns/Cities: Towns or cities with a population of at least 100,000 (1 lakh) are classified as Class I b) Million Plus Urban Agglomerations (UAs)/Cities: Cities with a population of 1 million (10 lakh) or more are classified as Million Plus UAs/Cities. There are 46 such cities in India C) Mega Cities: Urban Agglomerations with a population of 10 million (1 crore) or more are classified as Mega Cities. Within this framework, urban centres like Gorakhpur, whose population falls between 1 lakh and 10 lakhs, occupy a significant yet often overlooked position. They do not qualify as million-plus cities or megacities but still exhibit dynamic urban characteristics and growing environmental challenges. Therefore, Gorakhpur may aptly be referred to as a *mid-size city*—a category that captures its transitional urban status and makes it an ideal case for examining emerging environmental issues like traffic noise pollution. In recent decades, mid-sized Indian cities have experienced significant urban growth and expansion, particularly toward their peripheral areas and increased density in the central areas. The traffic situation of a mid-sized Indian city is distinct from that of a major metropolis or a highway. Public transport vehicles play a vital role in passenger movement in metropolitan areas. In contrast, the lack of public transportation in mid-sized Indian cities necessitates the usage of personal or private vehicles for most tasks. In addition to motorized vehicles, the traffic in mid-sized cities includes a significant proportion of non-motorized vehicles, such as rickshaws and bicycles [26].

Developing economies like India cater to heterogeneous or mixed traffic on their road network in mid-sized cities, which often have narrow carriageways [26]. Mixed traffic comprises of motorised engine, motorised EV and non-motorised vehicles. The Indian mid-sized city's traffic scenario is completely different from the western world as the presence of sizable share of non-motorized vehicles in the traffic stream which are many a time responsible for causing congestion, consequently rise to honking, and subsequently higher levels of noise [26] . With the growing population and increasing number of vehicles, mid-size Indian cities are experiencing a rapid rise in vehicular noise pollution. Residents of such mid-sized cities are traditionally unaware of the consequences of vehicular noise and associated health risks. Past studies discussed the adverse effects of traffic noise on human health, such as hearing impairment, sleep disturbance, cardiovascular outcomes, annoyance, speech interference, and loss of fertility [10-15].

Urbanization further exacerbate the challenge, with the World Bank estimating that over half of the global population now resides in urban areas, a figure projected to reach 70% by 2050 [27]. This demographic shift intensifies the prevalence of high-rise residential buildings situated near roadways, exposing occupants to heightened levels of vehicular noise. These buildings often cluster densely along major traffic arteries due to limited available land, compounding the issue and placing more residents at risk of noise-related health effects [28]. Apart from these residential buildings many open structure shops exists besides roads which comes directly under the territory of excessive noise pollution. The escalation of urbanization, coupled with the proliferation of high-rise residential structures in noise-prone areas, underscores the urgent need for effective mitigation strategies. Serious noise pollution is a direct outcome of the increased volume of traffic on the roads, and this problem is only getting worse with time. To address this challenge, understanding the fluctuation of noise along street, besides roads and vertical profiles of high-rise buildings is of importance. Such knowledge can inform urban planners in developing targeted mitigation measures to reduce road noise infiltration and enhance acoustic comfort in working areas in cities and high-rise residential environments.

1.5 Background of Noise Modeling

To lessen the impact of traffic noise, it is necessary to construct models that can predict it. The development of such models began in the 1950s, and since then, there have been many efforts in this area [29]. The study and modeling of traffic noise have progressed considerably over time, driven by the need to comprehend and reduce the impact of noise pollution on urban environments and human health. The early efforts (during1950s-1960s) to model traffic noise relied on fundamental traffic data, such as the number of vehicles and their speeds, incorporated into straightforward equations. During 1970s-1980s statistical methods came into existence i.e. The Federal Highway Administration's (FHWA's) traffic noise model, The International Organization for Standardization (ISO) played a key role in advancing traffic noise prediction by introducing standards like ISO 9613. This specific standard provided a framework for calculating how sound propagates outdoors. The 1990s and 2000s saw a leap in traffic noise modeling. Geographic Information Systems allowed for detailed spatial analysis, while advanced software like Sound PLAN offered more precise interpretation by considering factors like topography and weather. The modern era has brought exciting advancements. Machine learning, and AI are being used for increased accuracy in noise predictions. "Live Monitoring" with sensor networks feeds real-time data into models, providing immediate insights. Models now delve deeper, analysing the environmental and health impacts of noise pollution, informing stricter regulations and noise mitigation measures.

When it comes to highway and road planning and assessing new or predicted changes in traffic noise levels, traffic noise models are indispensable [30]. Today worldwide, organisations use prediction models such as the Federal Highway Administration's (FHWA's) traffic noise model, Calculation of Road Traffic Noise (CoRTN), Richtlinien für den Lärmschutz an Straben (RLS90), Acoustical Society of Japan (ASJ) road traffic noise prediction model, Common Noise Assessment Method in Europe (CNOSSOS-EU), 01dB Mithra, NMPB-Routes-96, Nord 2000, which stands as contemporary models [30-32]. The distinguishing factor among traffic noise models lies in the selection of the influential attribute utilized for the model development. Various countries exhibit diverse traffic circumstances and flow characteristics, hence the existence of a broad spectrum of models tailored to meet local requirements. The study and modeling of traffic noise have progressed considerably over time, driven by the need to comprehend and reduce the impact of noise pollution on urban environments and human health.

1.6 Problem Statement

Millions of people's health, happiness, and quality of life are negatively impacted by the ubiquitous and harmful problem of traffic noise pollution in urban areas across the globe. The constant din of motor vehicles not only disturbs the peace of residential neighborhoods, but it also endangers public health and the environment. Traffic noise can affect society in many ways given below:

a) Living conditions: People living in cities have their quality of life diminished when they are unable to enjoy outdoor activities, socialise, or relax in their houses due to the constant roar of traffic. Those who are constantly bombarded with loud noises report higher levels of stress, anxiety, and general poor health.
b) Impact on health: Insomnia, high blood pressure, heart disease, and cognitive impairment are just a few of the many health issues associated with long-term exposure to loud traffic. These negative impacts are more likely to occur in vulnerable populations, including children, the elderly, and those with current health problems.
c) Disruption of natural habitats and wildlife: The decibel level of traffic has an impact on both humans and other animals. In the long run, noise pollution can affect biodiversity and ecological harmony by interfering with animal communication, upsetting ecosystems, and changing the behavior of species.
d) Problems in urban planning: Dealing with the issue of traffic noise pollution is a major headache for city planners and politicians. Innovative strategies in urban planning, infrastructure construction, and transportation management are necessary to strike a balance between the demands of efficient transportation systems and the necessity to reduce noise consequences.
e) Social justice and equity: Low-income neighborhoods are more likely to be the targets of traffic noise pollution, which exacerbates pre-existing socioeconomic inequalities. Environmental injustices may persist since these populations may not have the means or political clout to fight for noise reduction policies.

There are still no real answers to the problem of traffic noise pollution, even though it is widely acknowledged as a major problem in urban areas. Conventional methods, including sound barriers and noise-reducing pavements, are expensive and difficult to apply on a broad scale.

1.7 Research Objective

In response to the growing concern over traffic noise pollution, several nations with advanced economies have developed traffic noise models to mitigate the problem. Building a traffic noise model policy can assist city planners in coming up with suitable measures to reduce traffic noise pollution. In this research, we have shed light on the escalating impacts of traffic noise pollution, with the primary objectives being as follows:

a) To develop a computer-based software for monitoring the traffic noise propagation under heterogeneous traffic for mid- size Indian city.

b) To develop vehicular source noise emission model for various vehicle type in heterogeneous traffic.

c) To develop model for the prediction of vertical distribution of traffic noise on the façade of high-rise building alongside the road bearing heterogeneous traffic.

1.8 Scope of the Study

Following is the scope of the study:

a) This study delves into the impact of traffic noise in a bustling mid-size Indian city, stemming from the dynamic flow of diverse traffic. By analyzing over 776 hours of meticulously collected traffic noise data ($L_{\mathrm{Aeq,1h}}$), the research aim to provide a comprehensive model that captures the essence of urban noise pollution in such environments.

b) In response to evolving vehicle design and emission regulations, this study undertakes a comprehensive analysis by collecting and scrutinizing over 13,684 data points from individual vehicle pass-byes. This extensive dataset enables a nuanced examination of noise levels, reflecting contemporary changes in vehicle technologies and regulatory standards. By doing so, the research aims to contribute vital insights into the impact of these advancements on urban noise pollution, informing future policies and technological innovations for quieter, more sustainable urban environments.

c) This study highlights critical concerns for residents living alongside roads in high-rise residential buildings under heterogeneous traffic enviroscape. It meticulously examines noise variations across vertical floor levels, revealing the quietest and loudest floors within residential structures. Utilizing scientific equations developed from heterogeneous traffic data, this research pioneers a predictive model for estimating traffic noise levels at different heights within buildings, offering invaluable insights for urban planning and residential design.

1.9 Organization of the Dissertation

The present research work was documented into five different chapters as follows:

a. CHAPTER 1 - This introductory chapter outlines the study's background, clearly defining the problem statement and detailing the objectives and scope of the research.

b. CHAPTER 2 - This chapter provides a literature review for the study. It examines different noise prediction models developed worldwide for both horizontal and vertical scales. Subsequently, the review explores how traffic noise varies with vertical height of buildings and other factors influencing noise propagation at different vertical levels. Following this discussion on literature of vehicular source noise emission models have been done.

c. CHAPTER 3 - This chapter deals with the field experiments conducted to obtain the dataset for mathematical analysis.

d. CHAPTER 4 - This chapter presents the results and discussion of the developed traffic noise predictive model for heterogeneous traffic flow in a mid-sized Indian city, specifically focusing on mid-block sections. The application of the K-Nearest Neighbor (K-NN) algorithm and Principal Component Analysis (PCA) technique is detailed. The findings from this section fulfil objective 1 of the research.

e. CHAPTER 5 - This chapter presents the results and discussion on the development of vehicular source noise emission model and prediction of highway traffic noise. It includes a discussion on development of vehicle noise emission curves for different vehicle categories, examining their respective emission level ranges and modeling them accordingly. The findings from this section fulfil objective 2 of the research.

f. CHAPTER 6 - This chapter presents the results and discussion on the prediction of road traffic noise at different floor levels of buildings in a mid-sized Indian city. The applicability of the Artificial Neural Network (ANN) model for developing the equation for traffic noise prediction is explored. In addition to the predictions, the variation of traffic noise with height is also discussed. The findings from this section fulfil objective 3 of the research.

g. CHAPTER 7 - This chapter delves into the key findings of the current research, articulating its core objectives and highlighting its significant contributions. Additionally, it offers insightful policy implications and explores promising avenues for future research, providing a comprehensive perspective on the study's broader impact.