CHAPTER-I

Introduction

Chapter Highlights

a. The critical role of transportation systems in the global shift from rural to urban living is emphasized, highlighting the significant impact urban transport has on the environment.

b. Siliguri City serves as a case study to assess urban transport and associated vehicular emissions. With its rapid growth, the city faces major environmental issues, particularly air pollution due to vehicular emissions.

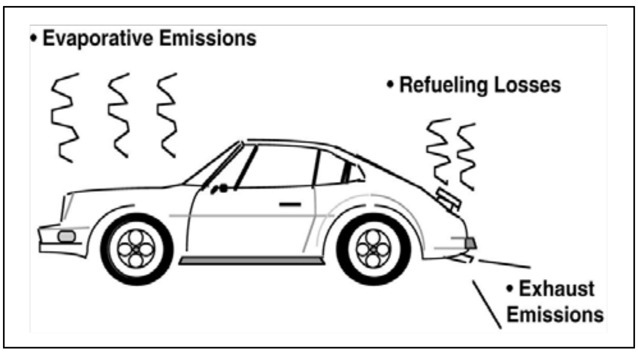
c. The chapter discusses the problem statement, research gap, objectives, hypothesis, sample selection, and research design. Additionally, it provides an organized overview of the thesis chapter by chapter.

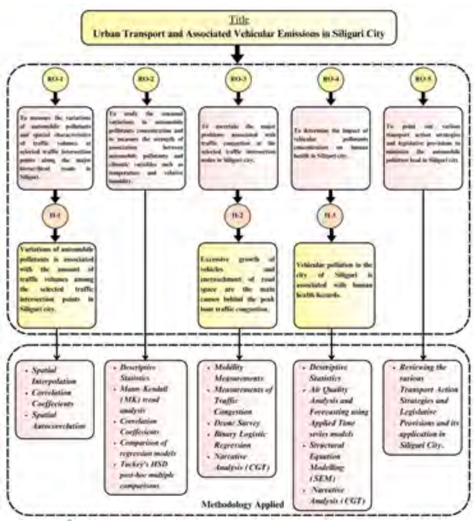
Graphical Abstract

Statement of the Problem | Objectives

Sample Selection | Research Design

Hypothesis | Research Gap





Chapter-I
Introduction

1.1 Introduction

In the contemporary landscape of global development, cities have emerged as epicenters of economic growth and prosperity. This transformation is largely underpinned by the phenomenon of urbanization, a process intricately linked to the development of transport systems. The story of urbanization is one of a gradual shift from rural to urban living, a trend that has reshaped societies across the world over the past two centuries (Sudarsanam and Singh 2004). From a mere 9 percent of the global population living in urban areas in the 1800s, the figure soared to approximately 46 percent by the turn of the 21st century. In India, this trend is particularly pronounced (Kavitha and Gayathri 2017). According to the 2011 Census, 31 percent of India's population resides in urban areas, comprising over 7933 towns and cities. These urban centers are not only population hubs but are also crucial in generating about 60 percent of the nation's Gross Domestic Product (GDP). It is projected that by 2026, around 535 million people, or 38 percent of India's population, will live in urban areas, increasing to 590 million by 2031 (Ong et al. 2018).

Urbanization is a complex process, reflecting a global shift from rural to urban living and resulting in an increasing proportion of the population residing in urban areas. This phenomenon is closely associated with modernization, industrialization, and the sociological process of rationalization (Cohen 2006). Urbanization not only denotes the growing percentage of people living in urban areas over time but also reflects the physical expansion and geographical spread of these areas. A critical aspect of urbanization is the development of transport infrastructure, which acts as the lifeline of burgeoning urban spaces. Transportation, characterized by the movement of people and materials, is akin to the arteries and veins in a human body, vital for the sustenance and growth of any economy. In countries like India, the role of transportation is particularly significant, as it underpins the development of civilization and economic progress (Ahmad and de Oliveira 2016). The modes of transportation are varied, encompassing air, rail, road, and water. This sector can be further categorized into infrastructure, vehicles, and operations. The relationship between transport infrastructure and urban growth is well-established

(Banister and Lichfield 2003). It is believed that transport infrastructure not only stimulates but also guides urban growth by improving accessibility.

The impact of globalization, which began in the early 1990s, has been significant on Indian industry and, by extension, on transport and mobility (Gupta et al. 2012). The opening of India's market to foreign investments led to an increase in foreign direct investment (FDI), global production, and cross-border trade. This global sourcing pattern, facilitated by the World Trade Organization (WTO) through trade and investment liberalization, has dramatically altered the economic landscape. India's adoption of the Liberalization, Privatization, and Globalization (LPG) model has positioned it as one of the fastest-growing economies in the world (Hummels 2007). The automobile industry, in particular, has been transformed by globalization, experiencing rapid growth and evolution (Humphrey et al. 2003).

However, the advancements in urban transport are not without their challenges. Urban road traffic and congestion significantly impact the urban air quality and the ecosystems (Kumar and Goyal 2011). In India, air pollution is a pervasive issue, especially in urban areas where motor vehicles are the major contributors. Vehicular emissions emanating from ground-level sources exert a substantial impact on the population. The continuous increase in motor vehicles has led to serious environmental and health impacts. Traffic-generated emissions are a major contributor to air pollution in urban areas, with motor vehicle emissions accounting for over 80% of air pollution in major cities (Rhys-Tyler et al. 2011). The environmental impact of transport has emerged as a global concern, encompassing a range of adverse effects such as climate change, global warming, and air pollution.

These environmental externalities of transport stem from two principal directions. Firstly, the increasing and concentrated economic activities in urban settlements, coupled with narrow roads, have led to a high concentration of pollutants due to congestion in the urban atmosphere (Huang et al. 2021). The effect is multiplied due to lack of policy initiatives in environmental quality, lack of coordinated efforts in the planning process and all these have been the major reasons for the transport induced environmental problems. A second dimension of environmental problems persists outside of the urban settlements due to the loss of bio-diversity, especially flora species in roads and nearby areas due to the expansion of road width and deforestation (Moughtin and Shirley 2005). In short, the transport-related environmental externality is mainly concerned with the problem of sustainability.

Air pollution by means of emission from road transport is one of the biggest problems in Indian cities. India has the second largest road network in the world and has become one of the biggest emitters of atmospheric pollutants from the global road transport sector. The deteriorating quality of public transport is driving people to move towards personalized transport, and thereby, the plying of these personalized vehicles encroached on the road space and created congestion it leads to environmental pollution (Guttikunda et al. 2014). A critical aspect of these challenges is the sustainability of the transport sector. Air pollution, primarily from road transport emissions, is a significant problem in Indian cities (Badami 2005). The shift from public to private transport has increased the number of vehicles on the road, leading to more congestion and pollution. Transport is a major emitter of greenhouse gases, accounting for a substantial portion of global emissions, with road vehicles being the largest contributors. The sector is responsible for significant emissions of Particulate matter ($PM_{2.5}$ and PM_{10}), NO_2, CO, and other pollutants, contributing to global warming and adverse health effects (OECD 1995). In India, the rapid growth in the number of motor vehicles, particularly in metropolitan cities, has been a major source of air pollution (CPCB 2000). Despite some improvements in air quality in certain areas, the overall situation remains critical. The concentration of vehicles, especially two-wheelers, in these cities contributes heavily to pollution levels (Platt et al. 2014).

Siliguri, in particular, has experienced severe air quality issues. In 2018, the Air Quality Index (AQI) readings in Siliguri were alarmingly high, indicating serious health risks (SJDA 2013; The Telegraph 2018; The Statesman 2018; Swiss Agency for Development and Cooperation 2018; CRCAP Report 2018). The primary contributors to this pollution have been identified as diesel vehicles and traffic congestion, compounded by administrative inefficiencies and lack of urban infrastructure such as flyovers (CDP Report Siliguri 2015). Therefore, it is vital to pay special attention to Siliguri's air quality and vehicular emission patterns in environmental studies. In the midst of these environmental challenges, the focus of the present study is poignantly set on the transport-related ambient air pollution in Siliguri. This research delves deep into the spatial dimensions of air pollution, intricately linking it with the prevalent road traffic congestion and its interplay with meteorological parameters. Moreover, it extends to assessing the impact of air pollution on human health, employing a perception survey to capture the lived experiences and impacts on the local populace. This study is not just an exploration of a local issue; it is a lens through which the global problem of environmental degradation is viewed and understood in a localized context. By examining the unique situation in Siliguri, the research offers valuable insights into how global environmental issues manifest at a local scale. It underscores the intricate relationship between urban transportation, environmental health, and human well-being, providing a nuanced understanding of these complex interdependencies.

1.2 Definition and Explanation of Air Pollution

The issue of air pollution is a significant environmental concern that poses a threat to contemporary society, with diverse consequences for both human health and the ecosystem. Numerous esteemed organizations have presented their respective definitions in an effort to encompass the vastness of air pollution and its consequences.

According to the World Health Organization (WHO), *"air pollution is characterized by the existence of substances in the atmosphere at levels that pose a threat to human health and the environment"* (WHO 2020). The definition put forth by the World Health Organization (WHO) underscores its comprehensive approach towards global health, emphasizing the urgent need to prioritize human welfare.

In a parallel vein, the United States Environmental Protection Agency (EPA) defines air pollution as *"The presence of chemicals or substances in the air that are harmful to the health and welfare of humans and other living organisms or that cause damage to the environment"* (EPA 2021). This definition places an emphasis on environmental effects.

According to the Central Pollution Control Board (CPCB) of India in 2019, *"The presence of a solid, liquid, or gas in the air at a concentration where it poses a risk to human health, animal health, plant health, infrastructure, or the environment."* This demonstrates a holistic understanding of the wide variety of negative effects.

Similarly, the European Environment Agency (EEA) in 2017 defined air pollution as *"The presence of particles, gases, and chemicals in the air that has the potential to harm human health and damage ecosystems."* The EEA highlights the importance of protecting health and biodiversity.

Furthermore, air pollution is defined as *"Substances in the air which have negative effects on individuals and the environment"* by the United Kingdom's Department of Environment, Food, and Rural Affairs (DEFRA 2013). The definition provided by DEFRA is concise and effectively conveys the fundamental nature of the concept without undue intricacy.

Woven through these definitions is a common thread: the pressing urgency to address the introduction of harmful substances into our atmosphere. This tapestry of definitions from renowned agencies worldwide evinces that air pollution is an all-encompassing quandary that calls for international collaboration to protect the health of both the planet and its inhabitants. There exists a consensus among esteemed organizations worldwide regarding the negative impacts of air pollution on both human health and the environment, as evidenced by their respective definitions of the phenomenon. The aforementioned definitions collectively underscore the pressing need and significant importance of addressing air pollution, thereby providing a foundation for customized policies and international cooperation.

1.3 Understanding the Silent Symphony of Global Air Pollution and its importance in different spatial scales

The urgency to comprehensively understand air pollution on a global scale is underscored by its multifaceted implications and wide-ranging impacts. While being a pressing environmental issue, air pollution also intersects with public health, socioeconomic stability, and geopolitical concerns, painting a complex picture that demands a thorough and integrated approach.

Air pollution is a critical global concern with transboundary effects that blur regional and national lines. Pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NOx), sulfur dioxide (SO_2), and ozone (O_3) can travel vast distances from their source, carried by meteorological factors and atmospheric circulation patterns. Therefore, emissions from one region can significantly impact air quality and public health in distant regions. For instance, studies have shown that emissions from industrial activities in East Asia can contribute to the levels of $PM_{2.5}$ observed in the western United States. The global nature of air pollution, therefore, calls for global-scale studies to better understand these broader pollution patterns and their associated risks.

Nine out of ten people in the world breathe air that contains high levels of pollutants, with the greatest exposure occurring in poor and medium-income nations, according to the WHO Urban Ambient Air Pollution Global Database (updated in 2018), which helps quantify the severity of the issue. With an emphasis on yearly mean concentrations of PM_{10} and $PM_{2.5}$, this database offers a worldwide evaluation of air quality, including almost 4,300 towns and cities in 108 countries.

The State of Global Air (2020) study, a joint effort by the Health Effects Institute as well as the Institute for Health Metrics and Evaluation, provides more information about the worldwide problem of air pollution. The report elucidates that air pollution, specifically fine particulate matter, ranks as the fourth leading risk factor for premature death worldwide, only exceeded by high blood pressure, dietary risks, and smoking. This report, combined with the Global Burden of Disease Study's (GBDS) comprehensive analysis of air pollution's impact on health, underscores the pressing need for a global approach to address air pollution.

One of the most comprehensive global observational epidemiological studies to date, the Global Burden of Disease Study (2018), offers strong evidence that air pollution significantly adds to the global illness burden. The research found that chronic respiratory disorders, lung cancer, heart disease, stroke, and lung cancer are among the noncommunicable diseases that may be accelerated by long-term exposure to polluted air.

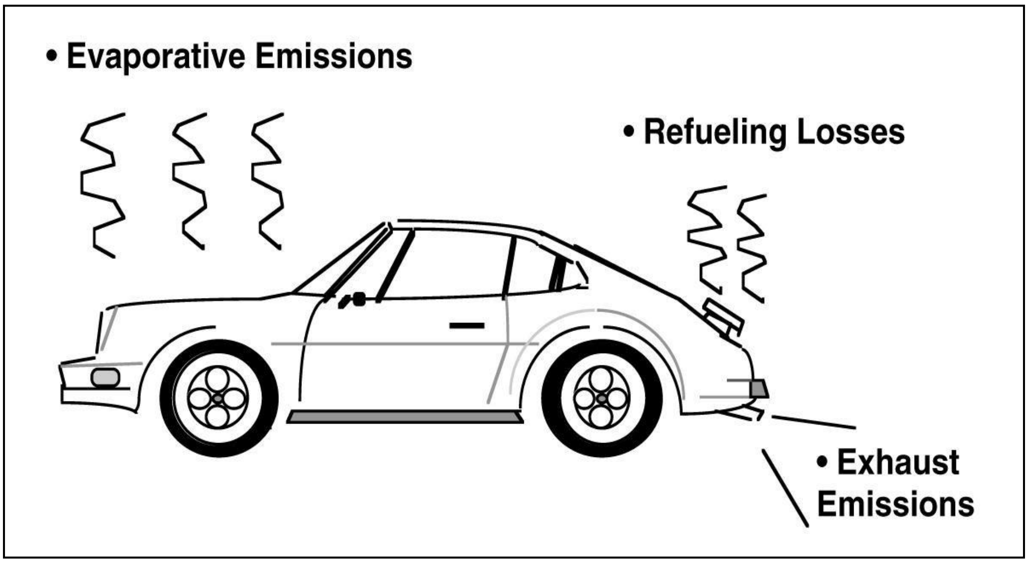
Meanwhile, the Air Quality Life Index (AQLI) by the Energy Policy Institute at the University of Chicago introduces a novel perspective by converting air pollution concentrations into their impact on life expectancy (AQLI 2016). It indicates that a person living in a region that adheres to the WHO guidelines for particulate matter would live, on average, two years longer than in a region that doesn't meet these guidelines.

Additionally, the "Clear the Air for Children" study of the United Nations Children's Fund (UNICEF 2015) offers helpful information on air pollution. The effects of air pollution on youngsters, who are already at a disadvantage, are highlighted in the paper. The paper claims that 300 million children reside in regions with air pollution levels six times higher than the international safe limit. These sobering numbers highlight the critical need for immediate, worldwide measures to reduce air pollution and save future generations.

Air pollution's complex interplay with climate change further emphasizes the necessity for global study. The burning of fossil fuels, a significant source of air pollution, also contributes to climate change by releasing vast amounts of pollutants. Addressing these pollutants could, therefore, significantly help in the global fight against climate change. The global understanding of air pollution also holds critical implications for international policy formulation and cooperation. The Paris Agreement, for instance, signifies how a comprehensive understanding of air pollution and its broader impacts can inform international policy, promoting cooperation and collective action for a sustainable future. Studying air pollution across various scales, i.e., global, national, and local, is essential for a comprehensive understanding and effective management of its multifaceted impacts. On a global level, it helps in tracking transboundary pollutants and understanding climate change dynamics; on a national level, it supports the formulation of policies and regulations that align with a country's unique sources and impacts; and on a local level, it enables targeted interventions to mitigate health risks and environmental degradation in specific communities. Ultimately, this multi-scale approach fosters international collaboration, national commitment, and community engagement necessary for creating a sustainable and healthy environment.

1.4 Concept of Vehicle Emissions

Air pollution is an ongoing, global environmental issue that directly impacts human health, biodiversity, and the overall ecosystem. The World Health Organization (WHO 2018) reports that around 7 million premature deaths annually are attributed to air pollution, highlighting the severity of this problem. This chapter examines the major



Source: US Environmental and Protection Agency (2012)

Fig.1.1 Different types of Vehicle Emissions contributors to air pollution: industry, agriculture, residential energy use, and vehicle emissions. As Siliguri is heavily polluted due to vehicle emissions, the concept of vehicle emissions needs proper understanding.

Vehicle emissions, a significant environmental concern, primarily originate from the byproducts of fuel combustion in vehicles. This process releases various toxic pollutants into the air, significantly impacting the environment (Böhm et al. 2022). In urban areas, particularly in rapidly expanding cities like Siliguri, the effect of these emissions is especially pronounced. The emissions from automobiles can be categorized into two main types: exhaust emissions and evaporative emissions (Chowdhury 2015). Exhaust emissions are the direct result of fuel combustion in the engine and are released through the vehicle's exhaust (See Fig. 1.1). These can be further divided into two categories: start-up emissions and running emissions. Start-up emissions occur when a vehicle is initially started and can be classified as either a cold start or a hot start (Yedla 2015). A cold start refers to starting a vehicle after a long period of inactivity, while a hot start occurs when a vehicle is restarted soon after being used, not allowing the engine sufficient time to cool. These start-up emissions tend to be higher due to the nature of the engine's operation after inactivity (Sawyer 2010). On the other hand, running emissions occur when the vehicle is in motion and the engine is at an elevated temperature, leading to more intensive fuel combustion and, consequently, a higher rate of pollutant emission. Evaporative emissions, another significant category, arise from fuel evaporation. These emissions include running losses and hot soak emissions, which occur when the engine is still hot at the end of a trip. Additionally, diurnal emissions are linked to changes in temperature that cause fuel evaporation.

The pollutants emitted from both exhaust and evaporative emissions are of great concern due to their harmful impact on the atmosphere and living beings (Kheirbek et al. 2016). In cities like Siliguri, the concentration of these pollutants is particularly high due to dense traffic and associated congestion. These pollutants, many of which are carcinogenic, pose significant health risks to both humans and the environment. They stem from engines powered by fossil fuels and are a byproduct of the city's transportation infrastructure and activity. The Central Pollution Control Board (CPCB 2013) highlights the importance of addressing these emissions, emphasizing their detrimental effects on urban environments like Siliguri.

1.5 Statement of the Problem

Numerous studies have highlighted the issue of air pollution from vehicular emissions in developed countries, yet research in developing nations remains relatively scarce. Recently, there has been a surge in studies focusing on air pollution in major Indian cities like Delhi and Kolkata, among others. However, research specifically addressing rapidly urbanizing areas like Siliguri is notably lacking. Over time, pollution in Siliguri has been on the rise, with air pollution escalating despite various control measures. In this context, vehicular emissions have emerged as a predominant source of air pollution in the city. The rapid increase in the use of fossil fuel-powered vehicles and significant traffic congestion at key intersections contribute substantially to Siliguri's air pollution.

Air pollution poses severe health risks, particularly respiratory diseases, which are a significant concern in developing country cities. The particulate matter emitted by vehicles, laden with toxic substances, primarily targets the human respiratory system, causing severe irritation and health hazards. These pollutants, widely dispersed in the environment due to the prevalence of running vehicles, pose a grave threat to human health.

The government has implemented numerous rules and regulations, including transport action strategies and legislative measures, to mitigate air pollution. These regulations have evolved over time, yet the issue of airborne pollution continues to escalate, further exacerbating health hazards. The rapid increase in vehicle numbers has led to heightened traffic congestion, exacerbating air pollution severity. In this context, the current research becomes increasingly relevant, addressing a global concern of environmental degradation. This study delves into the critical issue of air pollution in urban environments, specifically focusing on the deteriorating environmental quality and health hazards caused by vehicular emissions in Siliguri city. This research aims to provide an in-depth analysis of this pressing issue, contributing valuable insights to the broader discourse on urban environmental management.

1.6 Review of Literature

Literature on urban transportation covers a wide variety of issues. Various studies encompass automobile ownership and its uses, investments in transport infrastructure, land use patterns and their impact on transportation, the energy consumption of various transport modes, public and private transportation systems, quantification of externalities of transport, vehicular emissions, the impact of transport policies, etc. A review of literature and research outcomes regarding the various aspects of transportation related to vehicular emissions in the context of global and national levels is fairly an indication of the great amount of interest that the theme of automobile emissions has evoked among many researchers. The first part of the review focused on vehicular emissions in general, followed by vehicular Emissions due to different transport characteristics like delay events, road and intersection geometry, vehicle speed, and vehicle characteristics.

1.6.1 Conceptuality of Vehicular Emissions

While searching for literature, several articles and a thesis related to the conceptuality of vehicular emissions were identified for review in this section. Several works have justified the considerable information about vehicular emissions and related health hazards.

- **Borgia et al.** (1994), in their paper entitled *"Mortality among taxi drivers in Rome: a cohort study,"* pointed out the vehicular emission-related effects of lung cancer on taxi drivers.
- **Raaschou-Nielsen et al.** (1995), in their study entitled *"Traffic-related air pollution: exposure and health effects in Copenhagen Street cleaners and cemetery workers,"* stated that street cleaners and cemetery workers are subjected to effect traffic-related air pollution and the tendency to have a greater risk of chronic bronchitis and asthma.
- **Madsen et al.** (1998), in their study entitled *"Sequence analysis of porcine reproductive and respiratory syndrome virus of the American type collected from Danish swine herds,"* pointed out that vehicular emissions significantly affect the persons who are directly exposed to air pollutants. Their study in Denmark of 28,744 males found that there is an increased risk of lung cancer among taxi drivers and truck drivers when compared with other employees after adjustment for socioeconomic factors.
- **Faucet and Sevingny** (1998), in their work *"New directions: air pollution and road traffic in developing countries,"* have stated that inefficient transportation is the main cause of air pollution, which is more than 80% of total air pollutants. The continuous growth of urban areas in developing countries has resulting increased use of motorized transport, particularly road transport, which is the major source of vehicular emissions leading to ambient air pollution.
- **Goldberg et al.** (2001), in their paper entitled *"The association between daily mortality and ambient air particle pollution in Montreal,"* find out that ambient temperature and local meteorology affect the concentration and distribution of contaminants emitted by vehicles. Higher concentrations of sulphur dioxide are often

seen during winter, whereas increased amounts of ground ozone are often observed during summer. Additionally, they asserted that other climatic factors, such as humidity, wind velocity and direction, and overall air turbulence, significantly impact the spread of pollutants.

- **Tamura et al.** (2003), in their paper entitled *"Particulate air pollution and chronic respiratory symptoms among traffic policemen in Bangkok," pointed out that traffic policemen have more tendency to* particulate air pollution as well as chronic respiratory symptoms.
- **Randem et al.** (2004), in their work entitled *"Respiratory symptoms and airflow limitation in asphalt workers,"* pointed out that in addition to being exposed to traffic when commuting in a car, a significant segment of the population is also exposed to professions that require them to spend lengthy amounts of time on or near roads and highways, or in close proximity to traffic, such as asphalt workers.
- **Abou Chakra et al.** (2007), in their study entitled *"Genotoxicity of organic extracts of urban airborne particulate matter: an assessment within a personal exposure study,"* pointed out that due to reduced atmospheric dispersion and degradation reactions, cold weather can result in higher levels of contaminants in the ambient air. It has also been found that the genotoxic effects of $PM_{2.5}$ and PM_{10} are stronger in the winter months.
- **Balashanmugam et al.** (2012), in their study entitled *"Assessment of ambient air quality in Chidambaram, a South Indian town,"* pointed out that transport-related pollutants are the principal contributors to air pollution. They conducted an initial air sampling experiment at each of the eight sampling locations in Chidambaram, a semi-urban town in southern India, that lasted eight hours. The results indicate that the SPM, CO, SO_2, and NO_2 levels, which are considered to be criterion pollutants, have exceeded or are about to exceed the limitations.
- **Bhaduri** (2013), in her work entitled *"Vehicular growth and air quality at major traffic intersection points in Kolkata city: efficient intervention strategies,"* stated that the surge in travel demand has led to a significant expansion in the number of motor vehicles on the main roadways of Kolkata city. According to the Air Pollution Index (API), the concentration of suspended and respirable suspended particles is greatest among other automotive pollutants at the traffic junction sites in Kolkata city.
- **Roy Chowdhury** (2015), in his research paper entitled *"Traffic congestion and environmental quality: a case study of Kolkata City,"* pointed out that the city of

Kolkata has significant vehicle air pollution as a result of congestion. The survey conducted by the WBPCB in 2012-2013 revealed that there is a significant concentration of major vehicular air pollutants at certain major traffic points, such as Park Circus, Ultadanga, Esplanade, B.B.D Bag, Shyambazar, Gariahat, M.G Road crossing, and Science City Connector. This high concentration is primarily due to heavy congestion during peak hours.

1.6.2 Vehicular Emissions Due to Different Transport Characteristics

Various transport characteristics have their own contribution to the emission process. Below, different transport characteristics associated with vehicular emissions are discussed.

1.6.2.1 Vehicular Emissions by Delay-events as well as Driving Modes

- **Hunt et al.** (1982), in their study entitled *"The SCOOT online traffic signal optimization technique,"* stated that the optimization of traffic signal timing to reduce delay in response to fluctuating traffic using demand-sensitive split cycle and offset optimization technique (SCOOT) and urban traffic control (UTC) systems.
- **Hallmark et al.** (2000), in their article entitled *"Assessing impacts of improved signal timing as a transportation control measure using an activity-specific modeling approach,"* stated the impact of traffic signals upon emissions as measured by the MEASURE model, taking into account the signal duration component of CO emissions. Reduced CO emissions were a direct result of shorter wait times at traffic lights.
- **Rakha et al.** (2000), in their research work entitled *"Requirements for evaluating traffic signal control impacts on energy and emissions based on instantaneous speed and acceleration measurements,"* demonstrated that successful synchronization of signals can reduce emissions by up to 50 percent.
- **US Federal Highway Administration,** 2000 in the work entitled *"The Quality Improvement Program the Congestion Mitigation and Air,"* stated that When a vehicle slows down and stops at an intersection, the time it takes to achieve cruising speed is different from the time it would have taken if the vehicle had maintained its cruising speed through the junction. This discrepancy is called a control delay. In essence, it's the sum of all delays at the crossroads. It takes a lot of time and effort to get quantitative data on these factors. There are two types of delays that cars experience: the time-in-delay, which is always longer than the control-delay, and the stopped-

delay, which is the amount of time vehicles spend idling. A time-in-delay and a stopped-delay are averaged to get the control delay.

- **Rouphail et al.** (2001), in their work entitled *"Vehicle emissions and traffic measures: exploratory analysis of field observations at signalized arterials,"* pointed out the effects of traffic flow on real-time vehicle emissions. The vehicle's emissions rates were measured during each "mode of travel": acceleration, deceleration, cruising, and idle. They dug more into the control delay as it pertained to car emissions. According to the research, emissions were much lower while cars were in idle mode but increased when they were accelerated. Additionally, it was discovered that during control-delay, vehicle emissions were almost twice as high as when not-in-delay. This has also shown that the increase in emissions across all four modes of transportation is due to the transition between free flow and crowded flows.
- **Qiao et al.** (2002), in their study entitled *"Fuzzy logic-based intersection delay estimation,"* pointed out that delay is a straightforward metric for the aggravation that vehicles experience due to traffic lights at intersections and may be used to gauge the effectiveness of these intersections in calculating emissions. The delay event is a weighted average of the three modes: "idling," "acceleration," and "deceleration." During a wait, automobile pollution rates are higher than when a car is in motion. While delays like control-delay time-in-delay and stopped-delay are easy to quantify, monitoring traffic conditions at a traffic junction is wasteful. In order to construct correlations between vehicle emissions and delay events, these occurrences may stand in for any and all driving modes found at junctions.
- **Unal et al.** (2003), in their work entitled *"Effect of arterial signalization and level of service on measured vehicle emissions,"* pointed out that Vehicle emission estimations derived from dynamometer testing are now included in several traffic operations software packages. This makes it possible to track emissions, such as the impact of signal control on a specific area at any point in time and from any position while riding. Emissions may be defined by combining these readings under several situations, such as acceleration, deceleration, idle, as well as cruise.
- **Owen** (2005), in his study entitled *"Air quality impacts of speed-restriction zones for road traffic,"* showed that the operational parameters influencing vehicle emissions have undergone a significant change, with reduced traffic speeds playing a role. To add insult to injury, speed-control signals contribute to pollution via needless wait times, line formation, and approaching traffic speed-change periods. So, it's clear that

as traffic volumes rise above saturation, average delays and queue lengths increase, which in turn leads to more pollution. The average vehicle delay may therefore serve as a substantial metric for evaluating the performance of signalized intersections. The pollution consequences of these characteristics, however, vary according to the intersection's design and the roadways in question.

- **Gokhale** (2012), in his work entitled *"Impacts of traffic-flows on vehicular-exhaust emissions at traffic junctions,"* stated assesses the implementation of emission factors and the effect of traffic flow on CO, NO_2, along with PM emissions at two separate intersections. Field, experimental, and semi-empirical estimates of traffic parameters for unimpeded, interrupted, and crowded traffic-flow situations are all part of the study's three pollution-emissions scenarios. As a measure of traffic heterogeneity, it compares the two intersections' emission patterns. Based on the findings, it seems that emission factors at intersections need some tweaking in order to provide more accurate predictions of future air quality.

1.6.2.2 Vehicular Emission Due to Effects of Road and Intersections

- **Mustafa and Vougias** (1993), in their study, entitled *"Analysis of pollutant emissions and concentrations at urban intersections,"* showed that at intersections, traffic signals produce about 50 percent more emissions than roundabouts and signals cause greater HC emissions during heavy traffic, almost twice that at roundabouts.
- **Várhelyi** (2002), in his study entitled *"The effects of small roundabouts on emissions and fuel consumption: a case study,"* stated that replacing a signalized intersection with a roundabout result in a 29% average decrease in CO emissions, 21% in the NOx and 28% in fuel per car.
- **Kakooza et al.** (2005) in their study entitled *"Modeling traffic flow and management at un-signalized, signalized and roundabout road intersections"* pointed out that in terms of easing congestion, they found roundabouts perform better than un-signalized and signalized intersections with light traffic, but with heavy traffic, signalized intersections perform better.
- **Nesamani and Subramanian** (2006), in their study entitled *"Impact of real-world driving characteristics on vehicular emissions,"* observed that pollutant emission rates differ significantly from one road class to another and that local roads have the greatest impact. This is mostly because automobiles spend more time in acceleration mode at low average speed on the local streets.

- **Rosqvist and Planning** (2007), in their work entitled *"Vehicular emissions and fuel consumption for street characteristics in residential areas,"* pointed out that fuel consumption and exhaust emissions are heavily dependent on street design and street layout. Furthermore, well-designed roadways have the potential to enhance air quality, and they provide a transparent way to assess how different road designs affect air quality, as well as to lessen negative effects on the environment.

1.6.2.3 Vehicular Emission Associated with Driving Speed

For many reasons, emission variables determined in a controlled environment do not correlate with emissions in the actual world, even if they characterize a certain state of emissions. It is crucial to comprehend the impact of speed on emissions in all potential driving modes, especially at junctions.

- **Kuhler and Karstens** (1978), in their study entitled *"Improved driving cycle for testing automotive exhaust emissions,"* defined the proportion of different idle, acceleration, cruise, and deceleration operating modes in driving cycles. They also included additional variables, such as average acceleration, deceleration, mean duration of a driving cycle from start to end, and average number of acceleration–deceleration shifts during one driving period.
- **De Vlieger** (1997), in his study entitled *"On board emission and fuel consumption measurement campaign on petrol-driven passenger cars,"* found that, relative to normal driving, violent driving results in a sharp rise in fuel consumption and emissions.
- **Bogo et al.** (2001) in their work entitled *"Traffic pollution in a downtown site of Buenos Aires City"* pointed out that most studies have calculated the characteristic difference in emissions at average vehicle speed. The highest emissions of CO, particulate matter, and HC (including benzene) appear to occur at velocities of less than 20 km since these contaminants are products of incomplete combustion.
- **Ericsson** (2000), in his research paper entitled *"Variability in urban driving patterns,"* has found a major variability, the knowledge of which may be useful to formulate a strategy for modifying driving behaviors to minimize exhaust emissions.
- **Minocha and Saini** (2003), in their work on "Estimating Vehicle Fuel Consumption and Emissions Based on Instantaneous Speed and Acceleration Levels,*"* found that the speed of the engine significantly influences the fuel consumption and emissions of vehicles. In general, an increase in engine speed leads to higher fuel consumption,

resulting in a decrease in the air-fuel ratio, along with an increase in CO and HC emissions and a decrease in NOx emissions.

- **Colberg et al.** (2005) in their research work entitled *"Statistical analysis of the vehicle pollutant emissions derived from several European road tunnel studies"* pointed out how study on tunnel measurements affected emission variables as a function of vehicle speed. The results demonstrated that the concentration of NOx rose as the vehicle's speed increased. Criticisms of Vehicle Emissions.
- **Anilovich and Hakkert** (1996) in their research paper entitled *"Survey of vehicle emissions in Israel related to vehicle age and periodic inspection"* examined variations in CO and HC emissions as a function of vehicle age, duration since the last yearly test, and engine capacity, as well as a distinct correlation between the two.
- **An et al.** (1997), in their work entitled *"Development of comprehensive modal emissions model: operating under hot-stabilized conditions,"* stated that Vehicle emissions may vary with changes in engine load, depending on fuel supply and pollution control technology. Modern automobiles need more gasoline per cylinder to meet the demands of high speeds and acceleration, and NOx emissions tend to rise in tandem with engine loading.
- **Washburn and Mannering** (2001) in their work on *"Statistical modeling of vehicle emissions from inspection/maintenance testing data: an exploratory analysis"* pointed out that Vehicle factors, fuel parameters, operating circumstances, and environmental conditions are the four main types of vehicle variables that are known to impact emission rates. Vehicle parameters include characteristics such as category, mass, engine displacement, age, mileage, fuel delivery method (e.g., carbureted vs. fuel-injected), pollution control system, onboard computer control system, tampering control system, and inspection and maintenance record. The main ones to consider are form, oxygen content, fuel volatility, sulfur content, benzene content, lead and metal content, trace sulfur (catalyst impacts), and other fuel properties.
- **Chang and Yeh** (2006), in their work entitled *"Regional motorcycle age and emissions inspection performance: a Cox regression analysis,"* examined the impact of the age of the vehicle and found that the mean age of motorcycle disposal suggests the possibility of a serious problem with pollution.
- **Pandian et al.** (2009) in their study entitled *"Evaluating effects of traffic and vehicle characteristics on vehicular emissions near traffic intersections"* pointed out that operating conditions for vehicles mainly involve the cold or hot-start mode, average

vehicle speed, modal behaviors that cause enrichment, load (e.g. A/C, heavy loads, or towing), trip length and trips per day and driver actions effect, average vehicle speed. Altitude, humidity, atmospheric temperature, and the road grades are included in the vehicle-operating setting.

1.7 Research Gap

While numerous comparative studies have been conducted on vehicular emissions, a notable gap exists in research specifically targeting smaller urban areas like Siliguri. Existing studies have established those variations in emissions, particularly from diesel engines, are influenced by multiple factors such as engine type, engine state (transient or steady), and fuel type. Furthermore, the literature indicates a correlation between vehicle pollutant concentrations and various factors, including traffic congestion. However, a comprehensive, quantitative analysis characterizing vehicular emissions and their impact on human health in Siliguri has yet to be undertaken.

Environmental research, given its global relevance and urgency, has gained significant traction internationally, especially in the context of freight and passenger movement. In India, numerous national-level studies have been conducted, focusing primarily on environmental issues. Within West Bengal, much of this research is centered around the megacity of Kolkata, leaving smaller and other important cities like Siliguri with a dearth of such critical studies. This gap is particularly concerning for Siliguri, a major metropolitan city in West Bengal, which experiences considerable traffic congestion and a worrying trend in its Air Quality Index (AQI). The AQI in Siliguri consistently indicates a decline in air quality, primarily due to the high concentration of pollutants emitted from vehicles.

Therefore, it becomes imperative to address this research gap by conducting in-depth studies in Siliguri. Investigating the deteriorating air quality resulting from vehicular emissions is not only vital for local environmental management but also contributes to the broader understanding of urban air pollution dynamics. This research endeavor in Siliguri would not only fill a significant gap in the existing body of knowledge but also provide crucial insights for the development of effective strategies to combat air pollution in similar urban settings.

1.8 Study Area

Siliguri, a rapidly expanding metropolitan city, straddles the Darjeeling and Jalpaiguri districts in West Bengal, India. Nestled on the banks of the Mahananda River and at the foothills of the Himalayas, Siliguri sits at an average elevation of 122 meters (400 feet), making it a city with both geographical and strategic significance. It is the third-largest urban agglomeration in West Bengal, following Kolkata and Asansol, and plays a pivotal role in the region's trade and transportation networks. Over time, Siliguri has transformed from a small village to a bustling, commercially vibrant city (CDP Report Siliguri 2015). This transformation has been fueled by a significant influx of migrants, leading to rapid urban growth. The city's population has seen a marked increase, growing from 4.72 lakhs in 2001 to 5.13 lakhs in 2011, according to census reports (CRCAP Report 2018). This population boom has been accompanied by a complex and unorganized road network characterized by interlinking modality. The city's roads, which lack a definite hierarchy, serve both local and intercity traffic. The primary orientation of Siliguri's road network is North-South, with Hill Cart Road being a crucial corridor in this direction, followed by Burdwan Road. Other significant roads include Sevoke Road and Bidhan Road. The Siliguri Comprehensive Mobility Plan (SJDA 2013) reveals that arterial roads make up about 4.4% of the road network, sub-arterial roads comprise 3.2%, and inter-city and additional highway corridors account for 8.1%. The remaining 84.3% consists of other road types. Most of the road network (64%) features 1-2 lane undivided carriageways, and over half (51.3%) of these roads are in poor condition (Swiss Agency for Development and Cooperation 2018).

The number of registered vehicles in Siliguri has escalated exponentially over the years. From 1990-91 to 1995-96, the total number of vehicles increased by 188.4% annually. This growth continued, with vehicle numbers doubling from 42,482 in 1996 to 86,526 in 2004 – a staggering annual growth rate of 194%. From 2004 to 2014, the increase was 169%. Notably, the highest growth was observed in Light Motor Vehicles and two-wheelers, at 107% and 97.2% respectively (SJDA 2013). This growth results in huge air pollution in the city. For a more detailed exploration of Siliguri's evolving urban landscape and its environmental implications, including air pollution, a comprehensive description of the study area is presented in Chapter 2.

1.9 Research Objectives

1. To measure the variations of automobile pollutants and spatial characteristics of traffic volumes at selected traffic intersection points along the major hierarchical roads in Siliguri.

2. To study the seasonal variations in automobile pollutants concentration and to measure the strength of association between automobile pollutants and climatic variables such as temperature and relative humidity.
3. To ascertain the major problems associated with traffic congestion at the selected traffic intersection nodes in Siliguri city.
4. To determine the impact of vehicular pollutants concentration on human health in Siliguri city.
5. To point out various transport action strategies and legislative provisions to minimize the automobile pollution load in Siliguri city.

1.10 Hypothesis of the Study

1. Variations of automobile pollutants is associated with the amount of traffic volumes among the selected traffic intersection points in Siliguri city.
2. Excessive growth of vehicles and encroachment of road space are the main causes behind the peak hour traffic congestion.
3. Vehicular pollution in the city of Siliguri is associated with human health hazards.

1.11 Rationale for Sample Selection

This section provides a comprehensive description of the sample selection process for the perception survey for both the chapter 5 (*Perception regarding the causes of traffic congestion in Siliguri*) and Chapter 6 (*the impact of vehicular pollution on human health in the city*). The methodology employed ensured the reliability and representativeness of the survey through the application of a stratified random sampling approach. Given the inherent complexity of the target population, comprising traffic police, street hawkers, pavement dwellers, drivers, daily commuters, and local residents, conventional sampling techniques were insufficient. Therefore, the sample size was estimated using Daniels (1999) methodology tailored for infinite populations. This method facilitates the determination of the required sample size, accounting for parameters such as the confidence level, expected proportion, and margin of error.

$$n = \frac{Z^2 P(1-P)}{d^2}$$

Where, n = Sample size,

Z = Z statistics for a level of Confidence [for this study, Z=95%=1.96]

P= Expected Proportion [for this study, P=50%=0.5, *Macfarlane (1997)* suggested that 50% would lead larger sample size if the P is not sure]

d = Precision or margin of error [5%=0.05]

$$n = \frac{1.96^2 0.5(1 - 0.5)}{0.05^2}$$

n = 384.16 (384 approximately)

The application of this formula yielded an estimated sample size of approximately 384 respondents. However, to ensure the robustness of the dataset and practical feasibility, a total of 400 individuals were surveyed. Recognizing the diverse nature of the study population and the multitude of unique experiences and perspectives regarding air pollution in Siliguri, a stratified sampling approach was adopted. This approach involved categorizing the population into distinct strata based on occupation or residency. The strata encompassed traffic police, street hawkers, commuters, drivers, pavement dwellers, and local residents, each representing a unique segment of the population characterized by specific air pollution-related circumstances. Within each stratum, random sampling techniques were applied to select survey respondents. The random selection process ensured an equal and unbiased chance for every individual within a stratum to be included in the survey. This equitable sampling approach mitigated the risk of bias and amplified the applicability of the survey findings to the broader population. The adoption of a stratified random sampling approach was a deliberate choice, driven by the imperative to safeguard both the representativeness and statistical rigor of the research. This methodological rigor facilitated the comprehensive exploration of diverse perspectives and experiences concerning air pollution in Siliguri, aligning with the highest standards of research methodology.

1.12 Research Design

Geography, as a discipline, offers a diverse range of research methodologies due to its nature, which involves the interaction between humans and their natural environment. In the context of geographical research, there are three commonly used approaches: Quantitative, Qualitative, and a combination of both, known as Mixed methods.

The present study employs a hybrid approach, utilizing various methodologies across different chapters to validate hypotheses and address research objectives comprehensively. This approach incorporates both quantitative and qualitative methods, each tailored to specific objectives and detailed in their respective chapters. For a more in-depth understanding of the research methodology, including data collection and analysis techniques, please refer to the individual chapters where these details are elaborated upon. Figure 1.2 provides an overview of the overarching research methodology employed in this study.

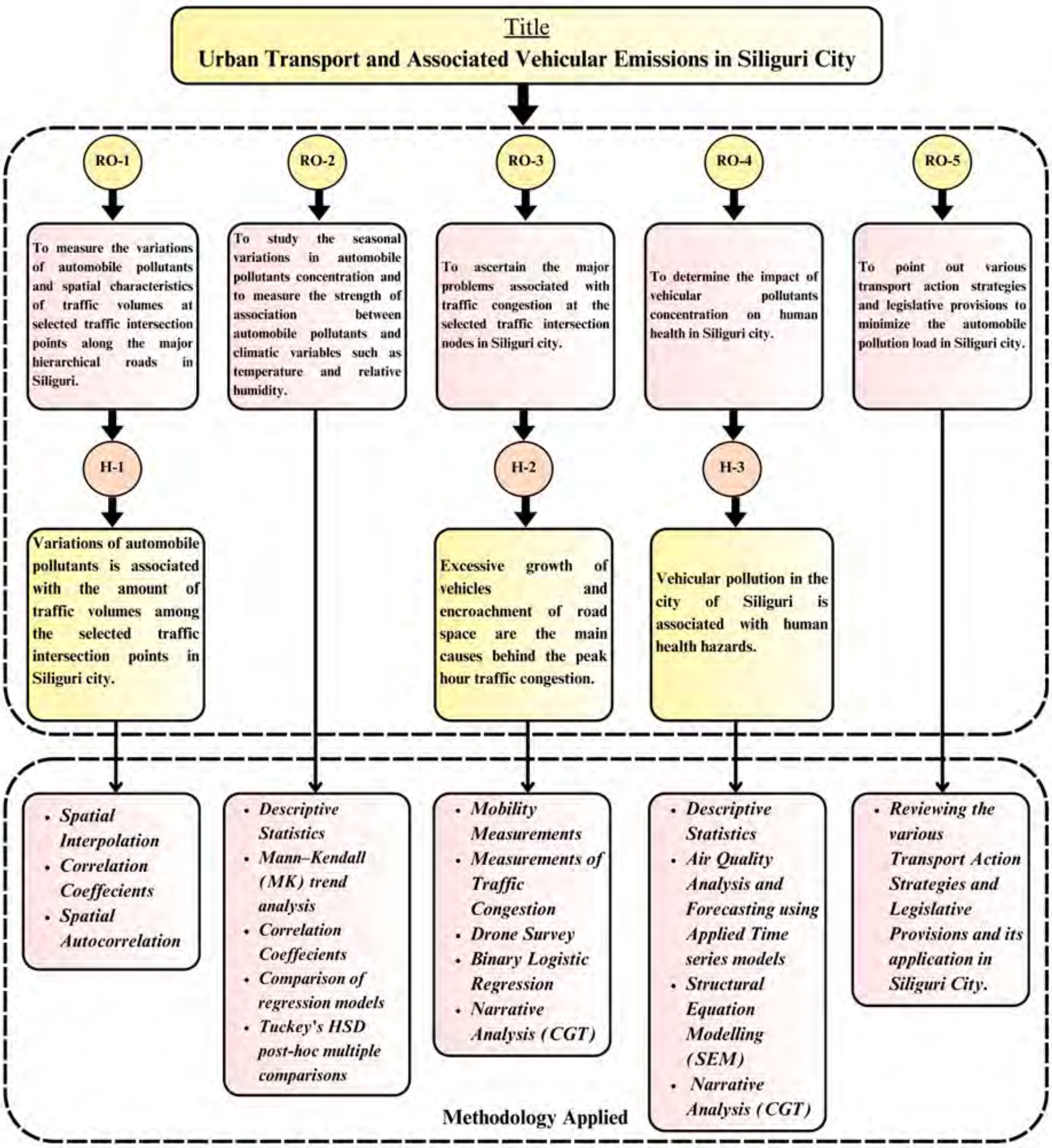


Fig.1.2 Research Design of the Study

1.13 Organization of the Thesis

This thesis, comprising eight meticulously structured chapters, offers a comprehensive exploration of air pollution in Siliguri, with a particular focus on vehicular emissions and their multifaceted impacts.

Chapter I: The introductory chapter sets the stage, presenting an array of concepts and definitions central to understanding air pollution and vehicular emissions. It lays out the statement of the problem, a thorough review of relevant literature, the research objectives and hypothesis, and an overview of the research design. This chapter serves as a foundational guide, paving the way for deeper explorations in the subsequent chapters.

Chapter II: This chapter paints a detailed portrait of the Siliguri Municipal Corporation (SMC), intricately describing the study area’s unique physical, demographic, and social characteristics. It delves into the historical evolution of the SMC, its physical attributes, and the socio-demographic fabric, including population growth, distribution, household densities, sex ratios, and other key demographic metrics. This chapter also examines the prevailing traffic issues and air pollution scenario in Siliguri, analyzing the impact of vehicular dynamics and congestion on urban life.

Chapter III: Here, the thesis delves into the spatial dynamics of traffic volume and consequent vehicular emissions, employing a variety of tools and GIS techniques. This chapter adeptly utilizes GIS to map traffic volume data against pollutant concentrations, highlighting the critical issue of air pollution in Siliguri. The chapter also explores key air pollutants, particularly $PM_{2.5}$ and PM_{10}, using spatial autocorrelation (LISA and Moran’s I) to reveal their monthly concentrations across various wards in Siliguri city.

Chapter IV: This chapter rigorously investigates the relationship between ambient air pollutant concentrations and meteorological parameters in Siliguri. Employing methodologies like trend analysis, Spearman correlation, MLR and MLNR models, and Tuckey's HSD post-hoc multiple comparisons, it establishes crucial findings that inform the broader research objectives.

Chapter V: Focused on traffic congestion in Siliguri, this chapter utilizes various analytical tools to assess traffic mobility and congestion levels at key intersections. It identifies primary causes of traffic congestion using a Binary Logistic Regression Model and explores its impacts through seven key issues, employing Constructivist Grounded Theory (CGT) and detailed fieldwork for qualitative insights.

Chapter VI: This chapter provides a thorough exploration of the impacts of vehicular emissions on human health in Siliguri. It combines time series models to predict air quality trends through 2025 and utilizes Structural Equation Modelling (SEM) based on population response surveys to assess the health impacts of vehicular pollution, offering valuable insights for policymakers and health advocates.

Chapter VII: Systematically structured, this chapter discusses transport action strategies and legislative provisions in Siliguri. It critically analyzes the measures to minimize automobile pollution, examines the governance and structural framework of the road transportation sector, and evaluates national transport policies in the context of their effectiveness and adaptability in Siliguri.

Chapter VIII: The concluding chapter synthesizes the overall findings and recommendations of the thesis. It encapsulates the key insights derived from the extensive research and proposes strategic suggestions, thereby offering a conclusive perspective on the study.

Together, these chapters form a cohesive and in-depth study, shedding light on the critical issue of vehicular pollution in Siliguri and proposing actionable strategies for mitigation and improvement of urban air quality.

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