THE STATISTICAL ANALYSIS OF THE RELATIONSHIP BETWEEN PARTICULATE MATTER WITH TRAFFIC AND METEOROLOGICAL PARAMETERS

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Işık University, School of Graduate Studies, Civil Engineering Master Program, 2023

This thesis has been submitted to Işık University School of Graduate Studies for a Master’s Degree. (MSc)

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IŞIK UNIVERSITY
SCHOOL OF GRADUATE STUDIES
CIVIL ENGINEERING MASTER PROGRAM

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APPROVAL DATE: 7/6/2023

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ABSTRACT

Particulate matter (PM) pollution has become a pressing concern due to its detrimental effects on human health and the environment. Understanding the relationship between PM and meteorological parameters, as well as the impact of traffic, is crucial for effective pollution control strategies. This thesis aims to analyze these relationships by employing an Ordinary Least Squares (OLS) regression model for $PM_{1.0}$, $PM_{2.5}$, and PM_{10} concentrations. A comprehensive dataset of PM measurements, meteorological data, and traffic-related variables is collected from various monitoring stations over a specific time period. Meteorological parameters such as temperature and wind speed, are obtained from corresponding meteorological stations, while traffic data includes vehicle counts and road characteristics. The initial analysis reveals significant associations between PM concentrations, meteorological parameters, and traffic impact. The OLS regression model is used to investigate the individual and combined effects of meteorological variables and traffic on PM levels. The results show that temperature, highway traffic and wind speed changes the PM concentrations, indicating that higher temperatures and traffic contribute to increased $PM_{1.0}$, $PM_{2.5}$, and PM_{10} levels. Wind speed demonstrates a negative correlation, suggesting that higher wind speeds are associated with lower PM concentrations due to dispersion effects. Furthermore, the model reveals that traffic-related variables, significantly influence PM pollution, with increased traffic leading to higher PM concentrations. The findings of this study provide valuable insights into the complex relationships between PM pollution, meteorological parameters, and traffic impact. These finding can assist policymakers and environmental agencies in formulating targeted measures to mitigate PM pollution, such as implementing traffic management strategies and improving urban planning. Moreover, the OLS regression model developed in this study can serve as a useful tool for predicting PM levels based on meteorological conditions and traffic patterns, facilitating proactive pollution control efforts.

Keywords: Particulate Matter, Meteorological Parameters, Traffic Impact, OLS Regression Model, Air Pollution, Pollution Control.

PARTİKÜL MADDE İLE TRAFİK VE METEOROLOJİK PARAMETRELER ARASINDAKİ İLİŞKİSİNİN İSTATİSTİKSEL ANALİZİ

ÖZET

Partikül madde (PM) kirliliği, insan sağlığı ve çevre üzerindeki zararlı etkilerinden dolayı acil bir endişe haline geldi. PM ve meteorolojik parametreler arasındaki ilişkinin yanı sıra trafiğin etkisini anlamak, etkili kirlilik kontrol stratejileri için çok önemlidir. Bu tez, PM1, PM2.5 ve PM10 konsantrasyonları için Sıradan En Küçük Kareler (OLS) regresyon modelini kullanarak bu ilişkileri analiz etmeyi amaçlamaktadır. Belirli bir süre boyunca çeşitli izleme istasyonlarından PM ölçümleri, meteorolojik veriler ve trafikle ilgili değişkenlerden oluşan kapsamlı bir veri seti toplanır. Sıcaklık ve rüzgar hızı gibi meteorolojik parametreler ilgili meteoroloji istasyonlarından elde edilirken, trafik verileri araç sayıları ve yol özelliklerini içerir. İlk analiz, PM konsantrasyonları, meteorolojik parametreler ve trafik etkisi arasındaki önemli ilişkileri ortaya koymaktadır. OLS regresyon modeli, meteorolojik değişkenlerin ve trafiğin PM seviyeleri üzerindeki bireysel ve birleşik etkilerini araştırmak için kullanılır. Sonuçlar, sıcaklık, karayolu trafiği ve rüzgar hızının PM konsantrasyonlarını değiştirdiğini ve daha yüksek sıcaklıkların ve trafiğin artan PM1, PM2.5 ve PM10 seviyelerine katkıda bulunduğunu göstermektedir. Rüzgar hızı negatif bir korelasyon gösterir, bu da daha yüksek rüzgar hızlarının dağılım etkilerinden dolayı daha düşük PM konsantrasyonları ile ilişkili olduğunu düşündürür. Ayrıca, model trafikle ilgili değişkenlerin PM kirliliğini önemli ölçüde etkilediğini ve artan trafiğin daha yüksek PM konsantrasyonlarına yol açtığını ortaya koymaktadır. Bu çalışmanın bulguları, PM kirliliği, meteorolojik parametreler ve trafik etkisi arasındaki karmaşık ilişkiler hakkında değerli bilgiler sağlar. Bu bulgular, trafik yönetimi stratejilerinin uygulanması ve kentsel planlamanın iyileştirilmesi gibi PM kirliliğini azaltmak için hedeflenen önlemlerin formüle edilmesinde politika yapıcılara ve çevre kuruluşlarına yardımcı olabilir. Ayrıca, bu çalışmada geliştirilen OLS regresyon modeli, meteorolojik koşullara ve trafik modellerine dayalı PM seviyelerini tahmin etmek için yararlı bir araç olarak hizmet edebilir ve proaktif kirlilik kontrol çabalarını kolaylaştırır.

Anahtar Kelimeler: Partikül Madde, Meteorolojik Parametreler, Trafik Etkisi, OLS Regresyon Modeli, Hava Kirliliği, Kirlilik Kontrolü.

ACKNOWLEDGEMENTS

I stand at the culmination of a remarkable journey, one that has been enriched by the support, guidance, and love of exceptional individuals and institutions. As I reflect upon the completion of my Master's thesis, I am profoundly humbled and immensely grateful for the contributions of those who have played an instrumental role in this achievement.

I would like to express my deepest gratitude to my esteemed advisor, Prof. Dr. Ali Sercan Kesten, for his invaluable mentorship and unparalleled expertise. His insightful feedback, constant encouragement, and patience have been crucial in shaping the direction of this research and enhancing the quality of this thesis.

I am profoundly grateful to Işik University for awarding me with a 100% scholarship, an act of generosity that allowed me to pursue my academic aspirations without the burden of financial constraints. The opportunities provided by this scholarship have enriched my academic experience and opened doors for personal and intellectual growth.

In this moment of reflection, my heart swells with appreciation for my parents. Their unwavering belief, endless encouragement, and boundless sacrifices have been the bedrock upon which my educational path was built. Their ceaseless support provided me with the strength to surmount challenges and pursue my dreams. I am deeply grateful for their unwavering love and prayers along this journey I have taken.

Mehran PANHWAR

To my family and my dear fiancée.

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ABBREVIATIONS LIST

PM1: Particulate Matter of Size 1.0 Microns

PM2.5: Particulate Matter of Size 2.5 Microns

PM10: Particulate Matter of Size 10 Microns

VE: Minute Ventilation

PNC: Particle Number Concentration

TAPM: The Atmosphere Pollution Model

MRA: Multiple Regression Analysis

PCE: Passenger Car Equivalent

CO: Carbon Monoxide

CO_2: Carbon Dioxide

NO_X: Nitrogen Oxides

NO: Nitric Oxide

NO_2: Nitrogen Dioxide

CH_4: Methane

SO_2: Sulfur Dioxide

HC: Hydro Carbons

GHG: Greenhouse Gasses

WHO: World Health Organization

AQG: Air Quality Guidelines

AQMS: Air Quality Monitoring Station

CHAPTER 1

INTRODUCTION

1.1 Background

Karachi, the capital of the Pakistani province of Sindh, is located in the southern part of the country along the Arabian Sea and serves as a major hub of transportation. Pakistan's two largest seaports, the Port of Karachi and Port Bin Qasim, and the country's busiest airport are situated in the city. Karachi has a history of human habitation spanning thousands of years, but the city as we know it today was established as a fortified village called Kolachi in 1729. Karachi is now considered as one of the fastest-growing cities globally, with a multicultural population that includes representatives from almost every ethnic group found in Pakistan. According to United Nations population projections; The current metro area population of Karachi in 2023 is 17,236,000, making it the world's 11th largest city.

Karachi experiences pleasant weather for a major portion of the year. May and June being the hottest months, with an average maximum temperature of around 93 °F (34 °C). The temperature can sometimes reach 105 °F (41 °C) in May and October, leading to uncomfortable weather conditions. January and February are the coolest months, with an average minimum temperature of approximately 56 °F (13 °C), and occasional cold winds can bring the temperature down to 40 °F (4 °C). The relative humidity varies from 58 percent in October, which is the driest month, to 82 percent in August, the wettest month. Karachi receives an average precipitation of 8 inches (203 mm), with majority of it occurring during 8 to 10 days in the months of June, July, and August.

Due to the lack of attention towards air pollution the city is suffering from worsening air quality. The major contributors towards the declining air quality are: high humidity in the region due to being close to the coast; which does not permit evaporation of stagnant water in some places, meanwhile exhaust fumes from factories and automobiles contribute to air pollution, in spite of land and sea breezes. Moreover, with rapid urbanization, high population density and heavy traffic the air quality in Karachi has decreased drastically.

Particulate matter is a broad term used to categorize air pollutants that consist of suspended particles in the air. These particles originate from diverse anthropogenic activities and can vary in composition and size (Morabet, Mouak, Khan, Ouadrhiri & Aneflouss, 2019). Particulate matter can be emitted directly into the atmosphere from both natural and anthropogenic sources. It can also form as secondary particulates within the atmosphere (World Health Organization [WHO], 2013).

The characteristics of particulate matter can be classified based on their physical attributes, which impact their movement and deposition, as well as their chemical composition, which determines their impact on human health (Cheremisinoff, 2002). The atmospheric concentration, composition, and particle size of suspended particulate matter at a specific sampling site are determined by various factors. These factors include the meteorological conditions of the atmosphere, topographical influences, emission sources, as well as inherent properties of the particles themselves, such as density, shape, and hygroscopicity (Fang et al., 2003).

In urban areas of Karachi, particulate matter is a major air pollutant, particularly respirable particulate matter with the diameter of less than 10 micrometer, which has a significant impact on human health. The frequent occurrence of particulate matter serves as a caution against accelerated urbanization and emphasizes the significance of creating a rational and a green city infrastructure. The majority of city air pollution is caused by vehicles, particularly those that are not well maintained (Tabassum & Begum, 2011). The mean concentration of PM_{10} at different locations of Karachi was 202.4 mg/m^3 (Hashmi, Shareef & Begum, 2018), exceeding the World Health Organization (WHO) recommended guidelines. According to the WHO, ambient and household air pollution is responsible for around 7 million deaths worldwide (World Health Organization [WHO], 2018). Therefore, an analysis of PM emissions in Karachi city is urgently required.

The aim of this study is to develop the relation between roadway traffic and particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) along with meteorological parameters.

1.2 Definition of the Problem

Air pollution in Karachi, much like other urban areas in developing nations, lacks sufficient research and understanding. Additionally, with the limited amount of research and understanding that is present it is known that the air quality in Karachi is highly deteriorated, posing substantial risks to human health (Moyebi et al., 2023). With rapid urbanization the air quality in the city is only getting worse with the passing of time.

One of the major contributors towards increasing PM levels in Karachi city is vehicular emission (Mansha, Ghauri, Rahman & Amman, 2012). Therefore, to get an assessment and the understanding of the current PM levels, caused mainly because of vehicular emission on Karachi’s major arterials and to analyze the relationship between PM and meteorological parameters, this study was conducted.

1.3 Objectives of the Research

The objectives of this research are:

1) To forecast the PM levels on four major arterials of Karachi.
2) To analyze the traffic volume on four major arterials of Karachi.
3) To estimate the 24-hour PM mean.
4) To develop the relation between roadway traffic and particulate matter (PM_{10}, $PM_{2.5}$ & $PM_{1.0}$) along with meteorological parameters.
5) To conduct a pollutant analysis on four major arterials of Karachi.

1.4 Importance of the Research

Air pollution is a significant issue that the world is currently confronting during this era, characterized by rapid industrialization and urbanization. In particular, particulate matter (PM) pollution represents a threat to both the environment and human health.

The potential health risks associated with particles are directly influenced by their size. Smaller particles with a diameter below 10 micrometers pose the most significant hazards as they can deeply infiltrate the lungs and, in some cases, even enter the bloodstream.

Exposure to such particles can have adverse effects on both the respiratory system and cardiovascular health. Extensive scientific research has established a strong correlation between exposure to particle pollution and a range of health issues, including: (Donaldson, Mills, MacNee, Robinson & Newby, 2005)

- Nonfatal heart attacks.
- Inflammation of the heart
- Irregular heartbeat.
- Aggravated asthma symptoms.
- Reduced lung function.
- Increased respiratory symptoms, such as airway irritation, persistent coughing, or difficulty breathing.
- Premature death among individuals with pre-existing heart or lung conditions.

Environmental degradation can occur when particles are transported over significant distances by wind and subsequently deposited on land or water. The consequences of this deposition can vary based on the particles' chemical composition and may include:

- Acidification of lakes and streams.
- Alteration of nutrient levels in coastal waters and major river basins.
- Depletion of soil nutrients.
- Harm to vulnerable forests and agricultural crops.
- Impacts on ecosystem diversity.
- Contribution to the effects of acid rain.

The study of Particulate Matter is significant due to the detrimental implications it has not only on human health but also on the environment. Moreover, this research will forecast the current PM levels and its association with meteorological parameters. Furthermore, the results of this research will offer a valuable understanding regarding the intricate connections between PM concentration, meteorological parameters, and the influence of traffic. These insights will be instrumental for policymakers and environmental agencies in developing specific strategies to address and reduce PM pollution. Lastly, this research can contribute to a more sustainable, resilient and a green city infrastructure, which is vital for mitigating the health risks associated with the PM pollution and improving the overall quality of the human life and environment.

1.5 Thesis Structure

This thesis is composed of 5 chapters, the details of each chapter are mentioned below in detail:

Chapter 1 presents a brief background about Karachi city and its yearly weather trend. Furthermore, a concise history about the air pollution in the city is also mentioned. Moreover, particulate matter (PM) its sources of emission, characteristics and its impact on human health is also discussed. Lastly, the definition of the problem, objectives of the research, importance of the research, and the structure of the thesis are included.

Chapter 2 presents a historical background of the topic, including information about particulate matter, the origin and the types of particulate matter, the adverse health effects that are faced due to short- and long-term exposure to particulate matter and the recent studies conducted on that scope.

Chapter 3 focuses on the locations of the monitored arterials, collection of the particulate matter, traffic volume and meteorological data. Lastly, the methodology adopted to analyze the collected data.

Chapter 4 presents the results of the data analysis.

Chapter 5 presents the conclusion and the future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Background

Throughout history, humans have inhabited a dusty environment that continues to grow increasingly polluted due to human activities such as industrial processes, traffic, and disasters. Dust, which was once solely derived from natural sources like rock and soil erosion, wind-blown sand, volcanic emissions, and occasional wood fires, has now been accompanied by artificial pollution introduced by the discovery and use of fire (Gatti & Montanari, 2015).

When combustion occurs, it not only releases gases but also generates particles whose composition depends on the materials being burned. The shape and size of these particles are primarily determined by the temperature at which the combustion takes place. Some particles are formed immediately at the site of combustion, while others are produced through condensation as the chemical elements or molecules are released and encounter colder temperatures away from the fire. Typically, the directly generated particles from combustion are mostly metallic, spherical, and hollow in shape. Their size decreases as the temperature of formation increases, ranging from tens of microns down to tens of nanometers. These particles often have a thin, fragile, crystalline crust that easily breaks into tiny fragments. Additionally, secondary particles, distinct from the primary ones described earlier, are produced at a distance from the combustion site and over time. They form through the photochemical condensation of gases such as nitrogen oxides, sulfur dioxide, ammonia, volatile organic compounds, water vapor, ozone, and naturally occurring free radicals in the atmosphere (Gatti et al., 2015).

Consequently, environmental pollution consists of micro- and nanosized particulate matter (PM) generated by both natural processes (Kemppainen, Tervahattu & Kikuchi, 2003) and human activities. Today's environment is burdened with substantial quantities of pollutants resulting from industrial activities, high-tech nanotechnological production (Colvin, 2003; Nel, 2006), combustion processes (Bosco, 2004; Kemppainen, 2003), waste incineration (Bethanis, 2004; Moon, 2002), and engine emissions (Murr, 2006; Gatti, 2015).

In the present era, global industrial activity is producing an unprecedented amount of dust, and what is particularly concerning is the rapid increase in this mass of pollution. This growth is especially prominent in emerging and developing countries where rapid economic development occurs without adequate consideration for health and environmental concerns (Gatti et al., 2015).

Air pollution arises from various origins, and the amount of particulate matter (PM) in the air is determined by the collective impact of these diverse sources. Thus, it is crucial to understand the sources present in different regions. Maintaining records of air pollution emissions is significant for assessing the influence of pollution on both air quality and climate.

Urban areas and major cities are often adversely affected by particulate matter (PM) originating from road traffic emissions, which can comprise hazardous components, such as trace metals. In order to ascertain the role of road traffic emissions in the environment, it is imperative to comprehend different emission attributes like source categories, vehicle fleet composition, and infrastructure conditions.

This chapter is divided in to two parts: the first part discusses about the adverse health effects that are faced due to short- and long-term exposure to particulate matter. Meanwhile, the second part focuses on the experimental studies that were conducted to assess the PM levels in Karachi and similar megacities.

2.2 Adverse Health Effects After Exposure to PM

The London smog of 1952 holds a significant place in history as one of the most crucial incidents of air pollution. Its impact resonated across multiple aspects, including scientific understanding, public awareness of air pollution, and government regulations. During December 1952, London experienced a severe air pollution event known as the Great Smog of 1952, or Big Smoke. The consequences of this smog on the human respiratory tract were devastating. According to initial medical reports in the weeks following the event, approximately 4,000 individuals were estimated to have died prematurely, with an additional 100,000 people suffering from various illnesses as a result. However, more recent research indicates that the actual number of fatalities was significantly higher, reaching around 12,000 (Bell, Davis & Fletcher, 2004). The Great Smog of 1952 stands as a tragic reminder of the severe health risks associated with air pollution episodes.

Numerous studies have been conducted to examine the relationship between PM exposure and cardiovascular disease. Long-term exposure to PM has been linked to elevated cardiovascular mortality rates, increased risk of various cardiovascular diseases, and signs of subclinical chronic inflammation in the lungs and subclinical atherosclerosis. Short-term exposure to PM has been associated with cardiovascular mortality and hospitalization rates, stroke mortality and hospitalization rates, myocardial infarctions, pulmonary and systemic inflammation, oxidative stress, changes in cardiac autonomic function, arterial vasoconstriction, and other health issues (Pope III & Dockery, 2006).

Daily levels of PM2.5 were observed at two locations in Karachi, Pakistan - Korangi and Tibet Center. Korangi is a neighborhood that accommodates both industrial and residential areas, whereas Tibet Center is a residential and commercial region situated in close proximity to a major highway. The monitoring period spanned six weeks, encompassing all four seasons. The average $PM_{2.5}$ levels were 5-7 times higher than the WHO guideline for a "good" day, with peaks reaching as high as 279 mg/m^3. According to the findings and as seen in developed countries, that higher levels of $PM_{2.5}$ are linked to a substantial increase in ER visits and hospitalizations for cardiovascular diseases, such as ischemic heart disease, hypertension, and myocardial infarction (Khwaja et al., 2013).

Between 2007 and 2012, a research found that brief exposure to outdoor air pollutants such as PM_{10}, NO_2, and SO_2 was linked to cardiovascular, respiratory, and overall non-accidental mortality in Istanbul. The findings revealed that the risk of mortality from air pollution may occur up to ten days after exposure (i.e., with a ten-day lag). Specifically, cardiovascular mortality was most strongly linked to daily average SO_2 levels, followed by NO_2 and PM_{10}. Additionally, both SO_2 and PM_{10} were significantly associated with respiratory mortality and overall non-accidental mortality in Istanbul (Çapraz, Efe & Deniz, 2016).

Emerging evidence suggests that short periods of high exposure to air pollution occurs while commuting. These occurrences have the potential to cause harmful health consequences. According to 2010 study conducted in Belgium, consisting of 55 people (38 males and 17 females). In a pairwise design, the subjects were first driven by car and then cycled along identical routes. Concentrations and lung deposition of PNC (particle number concentration; a measure of ultrafine particle) and PM mass were compared between biking trips and car trips. According to the findings the VE (minute ventilation; amount of air that enters the lungs per minute) while riding a bicycle is 43 times higher compared to car passengers. These variations are caused by increased VE (minute ventilation) in cyclists which significantly increases their exposure to traffic exhaust (Panis et al., 2010).

The PM_{10} levels in most developing countries around the world are in critical condition, with higher exceedances observed in the major cities' urban centers. While PM_{10} levels are decreasing in Europe and the USA, they remain critical in most Asian countries, particularly India and China. Studies have identified crustal matter, vehicular or traffic emissions, and biomass burning as the major sources of PM_{10} in most regions, although complex relationships exist between PM_{10} sources in different parts of the world. In addition to anthropogenic sources, dust storms also significantly impact PM_{10} variability across different continents. The seasonal pattern of PM_{10} is influenced by meteorological factors such as wind speed, temperature, and relative humidity. The $PM_{2.5}/PM_{10}$ ratio can be a useful marker for evaluating pollution sources and particulate matter distribution. Higher levels of PM_{10} are associated with increased instances of birth anomalies, decreased life years, and higher incidence rates of cardiovascular and respiratory diseases (Mukherjee & Agrawal, 2017).

2.3 Studies on PM Level Assessment

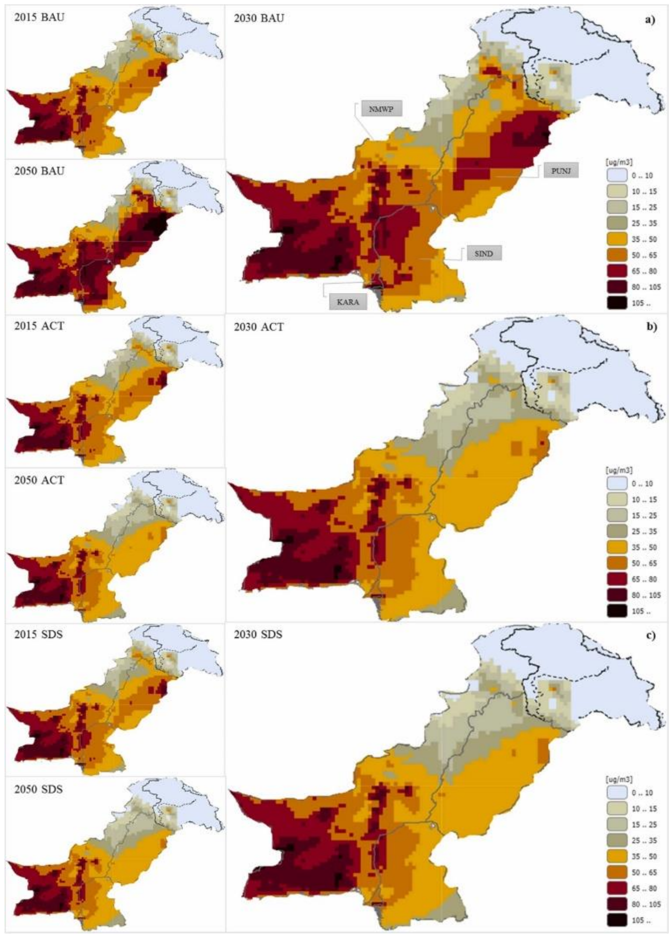

Figure 2.1 Ambient concentrations of $PM_{2.5}$

In Figure 2.1 the ambient concentrations of $PM_{2.5}$ in various scenarios are represented. These scenarios include:

I. The ambient concentrations of $PM_{2.5}$ in 2015 and the projections for the business-as-usual (BAU) scenario in 2030 and 2050.

II. The ambient concentrations of $PM_{2.5}$ in 2015 and the projections for the advanced control technology (ACT) scenario in 2030 and 2050.

III. The ambient concentrations of $PM_{2.5}$ in 2015 and the projections for the sustainable development scenario (SDS) in 2030 and 2050.

This study examines the co-benefits of implementing air pollution control measures and climate change mitigation strategies in Pakistan, considering both business-as-usual (BAU) and alternative scenarios. The findings indicate that the existing air pollution control measures in Pakistan are inadequate to meet the country's air quality standards under the BAU scenario. However, the study reveals that trends in air pollution can be reversed through the implementation of advanced control technology and sustainable development scenarios, particularly the Sustainable Development Scenario (SDS), which offers lower costs and greater reductions in greenhouse gas (GHG) emissions compared to the BAU and Advanced Control Technology (ACT) scenarios.

Under the BAU scenario, the study predicts that ambient $PM_{2.5}$ concentrations in Pakistan would increase by a factor of 1.5 by 2050, resulting in more than twice the number of premature deaths. However, integrating advanced control technologies into sustainable development policies would lead to a 76-88% reduction in SO_2, NOx, and $PM_{2.5}$ emissions by 2050 compared to the BAU scenario. Furthermore, the SDS scenario, by 2050, would halve $PM_{2.5}$ concentrations, potentially preventing 24% of total $PM_{2.5}$-related deaths (Mir, Purohit, Cail & Kim, 2022).

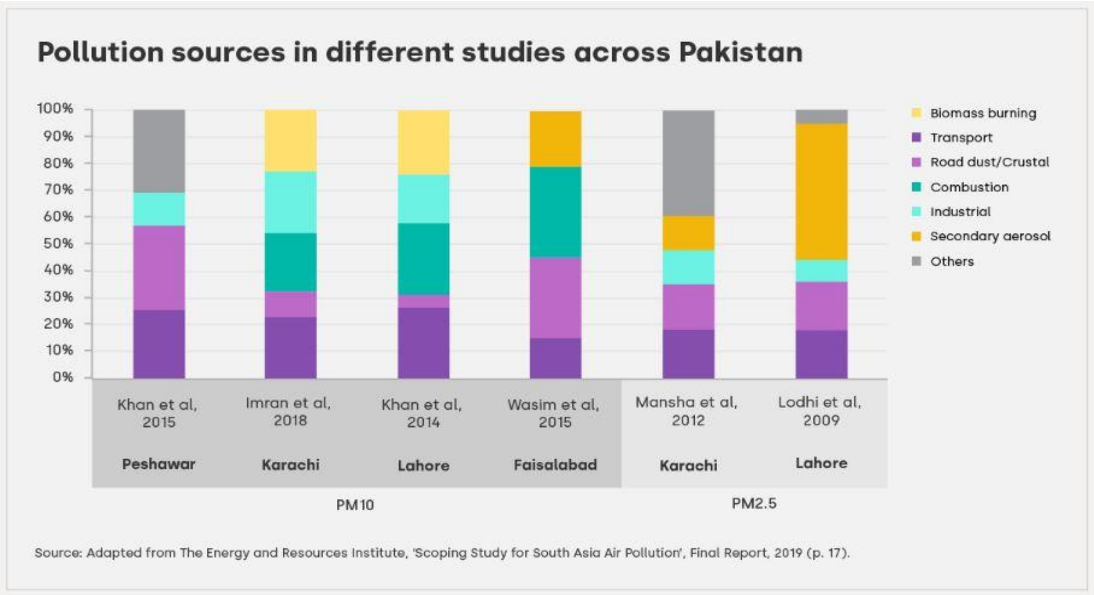

Figure 2.2 Pollution sources in different studies across Pakistan

Karachi's particulate matter mainly comes from various sources, including sea sprays, solid waste disposals and its incineration, fuel combustion using coal, oil, and gas, industrial effluents, soil dust due to strong wind turbulence, poor sanitation, and locomotive exhausts, with vehicle smoke being a significant contributor due to inadequate maintenance. Besides, in Karachi, where rainfall is infrequent, dry weather conditions cause pollutants to accumulate extensively in the atmosphere. Since the only way to remove pollutants during such conditions is through dry deposition (removal of aerosol particles and gases at the surface) by turbulent diffusion (mixing of concentrated contaminants with the surrounding air) and gravitational sedimentation (settling of particles under the action of gravity), the impact of such conditions on air quality should be considered along with other emission sources (Tabassum et al., 2011).

During the pre-monsoon period of March to April 2009, the measured concentrations of PM (particulate matter) at an urban site in Karachi were unexpectedly high. On average, the levels accounted for 75 µg/m³ ($PM_{2.5}$) and 437 µg/m³ (PM_{10}). The significant disparity between $PM_{2.5}$ and PM_{10} suggests that the city of Karachi is heavily influenced by a substantial amount of "coarse" dust. Throughout the sampling period, the average ratio of $PM_{2.5}$ to PM_{10} was 0.17. This ratio, lower than those observed in other cities such as Karachi, Cairo, Beirut, and Jeddah, which typically exhibit ratios around 0.4 or lower, indicates the transportation of particulate matter from nearby desert areas to the urban regions. Among the cities compared, Karachi displayed the lowest $PM_{2.5}/PM_{10}$ ratio, suggesting that local dust emissions, abrasion, and resuspension are the primary factors contributing to its elevated PM_{10} levels (Shahid et al., 2016).

The study conducted in Karachi, Pakistan analyzed the level of atmospheric pollution at 20 different locations in terms of trace gases and PM. The average concentration of SO_2 and NO_2 was found to be higher than the annual average of WHO guidelines at the sampling locations due to the high sulfur content in fossil fuels and heavy traffic density. However, the concentration of CO was lower than the WHO guideline values. The overall mean concentration of PM_{10} at residential, industrial, and commercial areas in Karachi was 202.4 mg/m^3. Although elevated concentrations of PM were observed in the city, they were still lower than most southeast Asian cities. The study concluded that the concentration of atmospheric pollutants in the environment signifies a decline in air quality in the city, with values exceeding permissible limits in commercial and industrial areas, as well as in residential areas with both commercial and residential status. The main source of pollution appears to be transportation, specifically due to congestion and fossil fuel emissions (Hashmi et al., 2018).

The rapid expansion of cities in Pakistan is primarily driven by rural to urban migration, driven by the pursuit of employment opportunities and better amenities.

However, this urbanization process has resulted in environmental degradation and an increase in air pollution levels. The deterioration of air quality can be attributed to various factors, including the absence of efficient mass transit systems and the prevalence of outdated trucks and two-stroke engines. Numerous governmental and international organizations have drawn attention to the escalating air pollution problems in major cities across Pakistan. The objective of this study was to present air quality measurements specifically focusing on the twin cities of Islamabad and Rawalpindi.

The levels of SO_2 observed at the majority of the sites examined were within the acceptable limits. However, Location 3 (Faizabad) exhibited higher values, reaching 40.4 $\mu g/m^3$, compared to the other sites. The concentrations of SO_2 at the remaining locations, namely Saddar, Airport, Blue Area, and NUST, were 28.9, 27.1, 22, and 22.4 $\mu g/m^3$, respectively.

As for NO_2, the overall concentrations were found to be within the permissible limits set by NEQS (National Environmental Quality Standards) and US-EPA (United States Environmental Protection Agency). The concentrations within the twin cities ranged from 29.6 to 36.3 $\mu g/m^3$. The highest values were recorded at Location 5, which is the Benazir Bhutto International Airport, while the lowest values were observed at Faizabad, Islamabad.

The overall concentration of O_3 (ozone) remained within the permissible limits as defined by NEQS (National Environmental Quality Standards) and USEPA (United States Environmental Protection Agency). However, peak values of O_3 were observed at NUST, Benazir International Airport, and Faizabad compared to other monitored sites, measuring 26.1, 24.3, and 20.9 $\mu g/m^3$, respectively. The concentrations of O_3 at the remaining sites were comparatively lower. Specifically, Saddar recorded an O_3 concentration of 18.3 $\mu g/m^3$, while the Blue Area in Islamabad exhibited the lowest values among all sites, with a concentration of 13.1 $\mu g/m^3$.

During the study period, the concentrations of CO_2 (carbon dioxide) were generally higher across all locations. Saddar in Rawalpindi had the highest value (409 ppm) due to heavy traffic congestion. Vehicular emissions were identified as the primary source of the elevated CO_2 levels, followed by the Westridge industrial area. Concentrations of CO_2 at the Blue Area and NUST in Islamabad were measured at 385.3 and 246.0 ppm, respectively. The Faizabad and Airport sites recorded CO_2 values of 375.9 and 368.8 ppm, respectively.

The highest concentrations of PM_{10} were recorded in Saddar, Rawalpindi, reaching 184 ppm, while the lowest values were observed at the Blue Area in Islamabad, measuring 121 ppm. The NUST and Airport sites showed PM_{10} values of 142 and 135 ppm, respectively.

Considering the limited data available on-air pollution in the region, the objective of this study was to monitor the levels of air pollutants in the twin cities, specifically focusing on emissions from vehicles, industries, and other sources. The findings of our study indicated that the majority of pollutant levels in the twin cities fell within the acceptable limits set by US-EPA and NEQS. However, higher concentrations of PM_{10} were observed across most sites. These findings emphasize the need for more comprehensive studies to gain a deeper understanding of air quality levels and associated issues throughout Pakistan, particularly in urban centers like Islamabad and Rawalpindi (Shahid et al., 2019).

Air pollution is a prevalent issue in most urban areas of Pakistan, necessitating the implementation of a monitoring strategy to assess and mitigate the problem. The concentration of pollutants is progressively increasing, surpassing national standards. With the exception of Karachi, average concentrations of CO, NO_2, and SO_2 were slightly below permissible limits. However, due to heavy traffic and commercial areas, concentrations of $PM_{2.5}$ and PM_{10} exceeded the allowable thresholds across all selected cities. Without planned countermeasures, additional pollutants such as CO, SO_2, and NO_2 are projected to surpass permissible limits as well. Based on the Air Quality Index (AQI) categories, Lahore and Karachi exhibited very unhealthy to hazardous air quality, as reflected in the Multidimensional Pollution Index (MPI) and overall poor air quality. The deteriorating ambient air quality in Lahore and Karachi, primarily due to $PM_{2.5}$ and PM_{10}, has significantly elevated AQI and MPI levels. The study establishes a strong correlation between AQI and MPI values, underscoring the importance of considering both when formulating policy recommendations to preserve healthy air quality in metropolitan areas. To effectively combat air pollution and promote sustainable urban management, it is imperative to focus on developing environmentally friendly and alternative energy sources, implementing careful traffic planning, advancing vehicle technology, increasing tree plantation efforts, and garnering support from relevant authorities (Nawaz et al., 2023).

The transportation sector is a significant contributor to air pollution, particularly in urban areas. A study was conducted to evaluate air quality at two major heavy traffic roads in Lahore, Pakistan. The study monitored particulate matter (PM) levels for twenty-four hours at each sampling site and noted the total number of vehicles passing by, which was then correlated with the PM levels. The study found that both vehicular congestion and meteorological factors had a positive correlation with PM levels. Additionally, the PM concentrations recorded were significantly higher than the recommended levels by the World Health Organization (WHO). The WHO guideline values for $PM_{2.5}$ are 10μg/m^3 (annual mean) and 25 μg/m^3 (24-hour mean), while for PM_{10}, the values are 20 μg/m^3 (annual mean) and 50μg/m^3 (24-hour mean). At site 1, the 24-hour average concentration of $PM_{2.5}$ was measured at 222 μg/m^3, which is nine times higher than the WHO guideline value. The 24-hour average concentration of PM_{10} at site 1 was recorded as 286 μg/m^3, which is six times higher than the WHO guideline value. At site 2, the respective 24-hour average concentration of $PM_{2.5}$ and PM_{10} were 302 μg/m^3 and 365 μg/m^3, which are twelve and seven times higher than the WHO recommended levels, respectively (Ali, Rauf, Sidra, Nasir & Colbeck, 2015).

A similar study conducted in Haripur city, Pakistan revealed significant concentrations of both $PM_{2.5}$ and PM_{10} particles in the air across various locations. The primary sources of PM pollution were attributed to human activities such as traffic, as well as industrial emissions. These findings indicate that Haripur city faces a higher risk to air quality due to anthropogenic activities, particularly the pollution generated by Hattar Industrial Estate. Additionally, the air samples collected demonstrated a high level of PM pollution in the ambient air of Haripur city. The study highlighted the inadequate monitoring, management, and enforcement of environmental regulations by federal and local authorities in Haripur city, contributing to the elevated levels of PM pollution. To mitigate this issue, it is recommended that regulatory bodies such as the Environmental Protection Agency, Health Department, and Local Government intensify their monitoring efforts of PM pollutants in different settings within Haripur city. Furthermore, addressing the problem of air pollution caused by PM requires implementing solutions such as planting trees in areas with high pollutant levels, promoting the use of personal protective masks, and establishing effective pollution control systems in industries operating within Hattar Industrial Estate, Haripur city, Pakistan (Asghar et al., 2022).

Between 2003 and 2013, a study was conducted in Istanbul, Turkey to investigate the changes in air quality. The concentration patterns of SO_2, CO, and PM were examined in 10 different districts of Istanbul. The data was collected from air pollution monitoring stations managed by the Istanbul Metropolitan Municipality Environmental Protection Department. The mean concentrations were compared on a monthly, yearly, and seasonal basis, with the winter season being from October to March and the summer season from April to September. The highest monthly average values for sulfur dioxide and CO were 12.61 and 949.19 µg/m^3, respectively, recorded in the Sarachane district. The Kartal district had the highest monthly average value for Particulate Matter at 72.07 µg/m^3. Over the period of 2003 to 2013, the monthly mean concentration values of SO_2 (P=0.012), CO (P=0.029), and PM (P=0.024) varied significantly among the different districts. Additionally, the study found that emissions of air pollutants (SO_2, PM, and CO) showed a substantial decrease between 2003 and 2013 (Yurtseven, Vehid, Bosat, Köksal & Yurtseven, 2018).

A research focusing on analysis of the concentrations of $PM_{2.5}$ in the Istanbul subway system. The study took real-time particulate matter measurements inside the passenger cabins, train driver's cabin, and on the platforms between September 2007 and January 2008, making it the first of its kind to investigate PM levels in the Istanbul subway system. The $PM_{2.5}$ concentrations inside the passenger cabins and train driver's cabin were lower than those recorded on the platforms, and the type of ventilation in the train could impact in-train particulate matter levels. Additionally, the depth of the underground station could affect the $PM_{2.5}$ levels at the platform. The concentrations of $PM_{2.5}$ inside the train ranged from 22-240 mg/m^3 on the M1 line and 1-140 mg/m^3 on the M2 line, with daily averages of 72.9 mg/m^3 and 61.2 mg/m^3, respectively. The particulate matter concentration levels were higher during rush hours in the mornings and evenings than during midday, with the Taksim subway station recording the highest $PM_{2.5}$ concentration levels of 181.7 mg/m^3. Taksim square is a cultural and entertainment center in Istanbul and a major commercial area, surrounded by bus stops and roads with a bus frequency estimated to be as high as 200 per hour, making traffic sources the primary contributor to air pollution at this location. The findings of this study suggest that commuters using the Istanbul subway may be exposed to high levels of $PM_{2.5}$ (Onat & Stakeeva, 2014).

Another study examined the changes in air pollution levels in Istanbul over a 10-year period from 2007 to 2017, with a focus on spatial and seasonal variations. The annual average level of PM_{10} was highest in 2007 at 67 µg/m^3, but decreased over the years, reaching a low of 46 µg/m^3 in 2017. The district with the highest PM_{10} levels was Esenyurt, which had a median level of approximately 100 μg/m^3 and a population of 846,492 in 2017. In contrast, Şile, a rural touristic area with a population of 35,131 people in 2017, had the lowest PM_{10} levels at a median of approximately 30 μg/m^3. PM_{10} levels were slightly higher during the heating season, with a median level of approximately 60-65 μg/m^3, than during the summer months, with a median level of approximately 50 μg/m^3. Additionally, the annual average limit for PM_{10} decreased from 150 μg/m^3 in 2007 to 48 μg/m^3 in 2017.

$PM_{2.5}$ was only measured at three air quality monitoring stations (AQMSs) in Istanbul starting in 2013: Kagithane-M, Ümraniye-M, and Silivri. The highest annual average $PM_{2.5}$ level was observed in 2013 at 30 μg/m^3, while the lowest was observed in 2016 at 23 μg/m^3. Among the three AQMSs, Kagithane-M had the highest $PM_{2.5}$ levels, followed by Ümraniye-M and Silivri. The monthly variation of $PM_{2.5}$ levels at all three AQMSs showed higher levels during the heating season with a median level of over 30 μg/m^3, and lower levels during the summer months with a median level of approximately 20 μg/m^3.

Over the study period, all three AQMSs showed a decrease in $PM_{2.5}$ levels, indicating a reduction in the sources of $PM_{2.5}$ emissions in the air (Mentese & Ogurtani, 2021).

Another research was carried out in Mitrena, an industrial area situated in Portugal, which exists alongside a densely populated urban region called Setúbal. Researchers developed a methodology to evaluate the impact of vehicles on atmospheric aerosols. This methodology proved useful in assessing population exposure to road traffic emissions and assessing the effectiveness of mitigation actions. The methodology was validated using statistical quality indicators for the meteorological components of the The Atmosphere Pollution Model (TAPM), which showed reliable behavior with minimal differences between simulated and measured values. The methodology focused on estimating PM_{10} traffic emissions from resuspension and exhaust sources. Results indicated that dust resuspension significantly contributed to PM_{10} concentrations, with heavy vehicles being the primary contributor to PM_{10} emissions from exhaust (Garcia, Domingues, Gomes, Silva & Almeida, 2013)

Lastly, in another study in Delhi, India during the period of 2000 to 2010, PM_{10} emissions increased by 25%, from 8.5 Gg to 10.6 Gg. A significant reduction in PM_{10} emissions was observed during 2001-2002, as a result of measures implemented by the Delhi government to reduce transport emissions in the region. However, after 2002, there was a gradual increase in PM_{10} emissions. The largest reduction in PM_{10} emissions was seen in 2006, where it dropped from 9.8 Gg in 2005 to 7.9 Gg. This decrease may have been due to the phase-out of diesel vehicles in the public fleet and the implementation of Bharat Stage III norms in 2005, as well as the use of cleaner CNG fuel in buses and auto-rickshaws. Since 2006, PM_{10} emissions have been on the rise again, which could be attributed to the continuous increase in the vehicle population across all vehicle types (Sindhwani & Goyal, 2014).

CHAPTER 3

METHODOLOGY AND DATA ANALYSIS

This chapter discusses about the locations of the monitored arterials, collection of the particulate matter, traffic volume and meteorological data. Lastly, the methodology adopted to analyze the above-mentioned data.

Karachi being the largest and most populous city of Pakistan with an area of 3780 km^2 is selected for this experimental study, to study the relationship between traffic density and particulate matter of different sizes along with the meteorological parameters.

Karachi is a megacity and serve as the economic, cultural, and historical hub for Pakistan. Moreover, the city is highly urbanized and densely populated. Karachi is best known for its busy streets, vibrant markets, and modern skyscrapers. Furthermore, Karachi is a coastal city, located on the shores of Arabian Sea.

Due to the rapid urbanization, high population density and heavy traffic the city suffers from worsening air quality, which is adversely affecting the health of its citizens. As air pollution increases the PM levels of Karachi are also increasing, which is an alarming situation for the people living in Karachi. Therefore, there is an urgent need to analyze the air quality data of Karachi so that an understanding of the PM levels can be developed and a solution could be derived to overcome the increasing PM levels.

3.1 Data Description

To study the relationship between particulate matter with the rise and fall of traffic and traffic density. With this aim, four major arterials of Karachi were selected. Location of the arterials were selected focusing on the basis of variability in the traffic pattern throughout the day which will ultimately result in a unique data set.

3.1.1 Monitored Arterials

The details of the monitored arterials are mentioned below:

Table 3.1 Coordinates of the Selected Arterials

ARTERIALS	**GPS COORDINATES**	
	Latitude	Longitude
Shahra E Faisal Road	24°52'44.8"N	67°06'24.5"E
New M.A Jinnah Road	24°52'59.8" N	67°03'13.9" E
North Karachi Road	24°58'21.7"N	67°03'59.4"E
Rashid Minhas Road	24°55'48.3"N	67°05'12.3"E

Figure 3.1 Locations of the Selected Arterial

The four major arterials selected for this experimental study are:

1. Shahrah E Faisal Road: It is a major arterial in Karachi that runs 18 km (11 mi) in length. It is among the most congested routes in Karachi, often causing traffic jams. The distance from central Karachi to this location is 13.7 kilometers (8.5 mi).
2. New M.A. Jinnah Road: Situated near the mausoleum of the founder of Pakistan, Muhammad Ali Jinnah. The New M.A. Jinnah road serves as the major arterial for the traffic coming from nearby areas and going towards downtown Karachi. The distance from central Karachi to this location is 11.8 kilometers (7.3 mi).
3. North Karachi Road: Situated in the North of Karachi, this route is the oldest in Karachi, and during peak hours, there is a high traffic density that leads to congestion. The distance from central Karachi to this location is 3.6 kilometers (2 mi).
4. Rashid Minhas Road: It is one of the busiest roads and a major arterial in Karachi, it stretches 11 km (6.8 mi) in length. The distance from central Karachi to this location is 5.9 kilometers (3.6 mi).

3.2 Data Collection

For data collection the main objective was to have the traffic volume data, traffic count data, meteorological data, as well as the PM data for the above-mentioned arterials. For traffic data collection a camera was placed on the pedestrian bridge to record the traffic volume. A 10-minute time interval was selected and the number of vehicles passing through the 10-minute time bracket were noted and divided in to six vehicle classes (cars, bikes, rikshaws, pickups, busses and trucks). Similarly, the meteorological data (temperature and wind speed) was also collected on the roadway median and in the same 10-minute time interval. Lastly, the PM data ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) was also recorded in the same 10-minute time interval, the PM data was also collected on the roadway median. The duration for the data collection on every arterial was 16 hours from 0600-2200 hrs. The data was collected in the months of April and May of 2022. The above-mentioned data was collected on week days only.

3.3 Methodology

Multiple Regression Analysis (MRA) is a statistical technique used to examine the relationship between a dependent variable and multiple predictor variables. The results of MRA are expressed as coefficients, which represent the estimates. MRA allows us to determine the extent to which each independent variable contributes to the variation in the dependent variable (Petchko, 2018).

$$y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + \epsilon$$

Where,

• y = the predicted value of the dependent variable

•B_0 = the y-intercept (value of y when all other parameters are set to 0)

•B_1X_1 = the regression coefficient (B_1) of the first independent variable (X_1) (a.k.a. the effect that increasing the value of the independent variable has on the predicted y value)

•B_nX_n = the regression coefficient of the last independent variable

• ε = model error (a.k.a. how much variation there is in the estimate of y)

In the case of this study the dependent variable is PM, while the independent variables are the following: temperature, wind and PCE count. Meanwhile, the B values are the regression coefficient for temperature, wind and PCE count.

The size and sign of regression coefficients are significant. The size of the coefficients indicates the individual contribution of each predictor variable to the variance in the dependent variable, while accounting for the effects of all other predictor variables in the model. When standardized (as β), the coefficients provide a measure of the relative importance of each variable, enabling comparison between predictors. The sign of the coefficients is also important and is evaluated in relation to the expected or hypothesized sign based on theory. (Petchko, 2018).

In assessing the statistical significance of each estimated coefficient, the p-value (or significance probability) associated with the coefficient is compared to a predetermined level of significance. If the p-value is smaller than the chosen level, the coefficient is considered statistically significant, indicating strong evidence against the null hypothesis. Conversely, if the p-value is larger, the coefficient is interpreted as nonsignificant or lacking statistical significance. A small p-value (<0.05) suggests substantial evidence against the null hypothesis, while a large p-value (>0.05) indicates weak evidence against the null hypothesis. The reporting and interpretation of null hypothesis significance can vary, with common significance levels being 1%, 5%, and 10%. Results are often described as "statistically significant at the 1% (or 5%, or 10%) significance level." For this study, a 5% significance level is adopted. (Petchko, 2018).

Goodness-of-fit statistics are utilized to assess how well the tested model explains the data. These statistics measure the extent to which the combination of predictors accounts for the variance in the dependent variable. The F-statistic is employed to determine if all coefficients in the model are collectively statistically significant. On the other hand, R^2 (or adjusted R^2) represents the overall proportion of variance in the dependent variable that is explained by the combination of all predictor variables. In the case of time-series regression, an R^2 value of 0.8 or higher is often considered indicative of a "good" fit (Petchko,2018).

CHAPTER 4

STATISTICAL MODELLING

This chapter is dedicated to the analysis of the collected data and its comparison with different parameters.

4.1 Traffic Data Analysis

This section discusses about the real traffic count and passenger count equivalent. Both of them are discussed in detail below:

Real traffic count refers to the actual number of vehicles passing through a specific location on a road or intersection over a given period. It is a quantitative measure used to assess the volume of traffic at a particular point, this goal can be achieved by a number of different methods, but for this experimental study the real traffic count was obtained through placing a video camera at specific locations and capturing real-time traffic footage, which later was analyzed to count vehicles.

Meanwhile, the Passenger Car Equivalent (PCE) is a unit used to represent the impact of a large vehicle on a road by expressing it as the number of equivalent passenger vehicles. PCE factors are utilized to convert the count of heavy vehicles into an equivalent count of passenger cars. This conversion allows for the simplification of traffic analysis by representing a mixed flow of heavy and light vehicles as a traffic stream composed entirely of passenger cars.

Table 4.1 Vehicles Type & Their Respective PCE Factors

VEHICLE TYPE	PCE FACTOR
CARS	1.00
MOTORCYCLES	0.25
RICKSHAWS	0.50
PICKUPS	1.50
BUSSES	2.50
TRUCKS	3.00

The roadway traffic data was analyzed and compared with their respective Passenger Count Equivalent factors, for PCE factors refer to Table 4.1. Both real traffic count and PCE count are valuable tools in traffic analysis, but they serve different purposes. Real traffic count provides direct information about the number of vehicles utilizing a road, while PCE count helps in evaluating the impact and capacity implications of different vehicle types on traffic flow. Therefore, an analysis of real traffic count and passenger count equivalent is made to compare the difference between them.

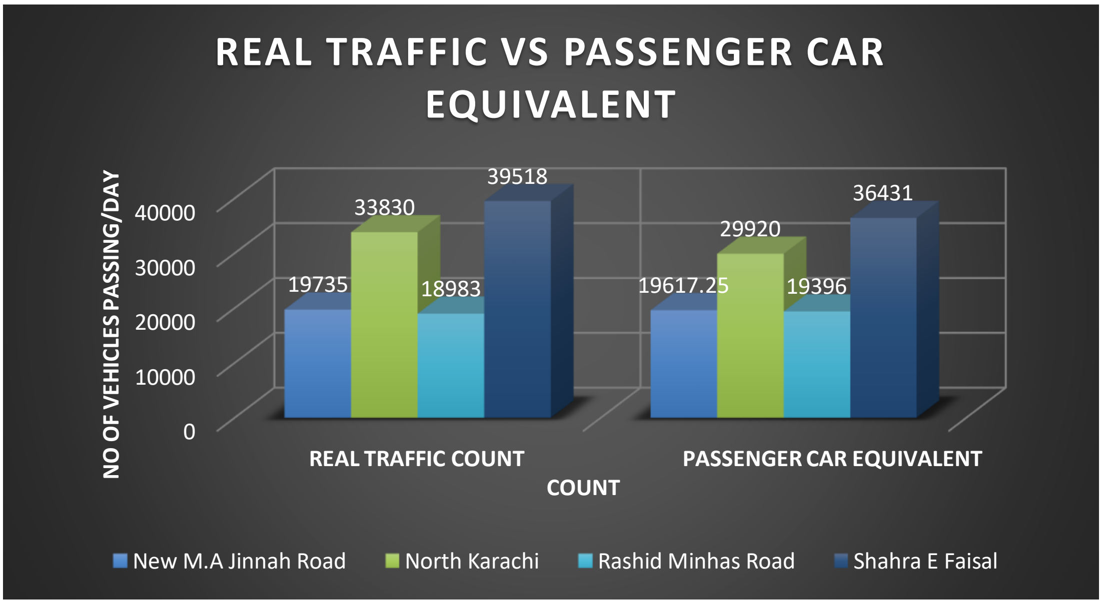

Figure 4.1 Real Traffic Count VS PCE Count

It can be observed from Figure 4.1 that all the arterials have less PCE count than the real traffic count except Rashid Minhas Road; where the PCE count is more than the real traffic count. That is because an equal or higher PCE count means that the arterial is subjected to more heavy traffic.

4.2 PM Data Analysis

This section discusses the levels of particulate matter present on the selected arterials and its relationship with different parameters. Furthermore, the main three sizes of particulate matter were taken in to consideration; $PM_{1.0}$, $PM_{2.5}$ and PM_{10} for the analysis.

4.2.1 Statistical Analysis of the Arterials

The main purpose of this multiple linear regression analysis was to understand to what extent is the Particulate Matter influenced by the three independent variables.

PM Analysis for New M.A. Jinnah Road:

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM1.0	.957	.916	.904	21.824

Regression Equation:

$\hat{Y}$= - 0.396 (x_1) -7.024 (x_2) + 0.466 (x_3) For $PM_{1.0}$

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM2.5	.952	.908	.895	27.732

Regression Equation:

$\hat{Y}$= - 0.012 (x_1) + 4.063 (x_2) + 0.390 (x_3) For $PM_{2.5}$

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM10	.955	.912	.900	29.164

Regression Equation:

$\hat{Y}$= - 0.115 (x_1) + 4.114 (x_2) + 0.440 (x_3) For PM_{10}

Where, x_1= Temperature (°C), x_2= Wind (m/s), x_3= PCE Count

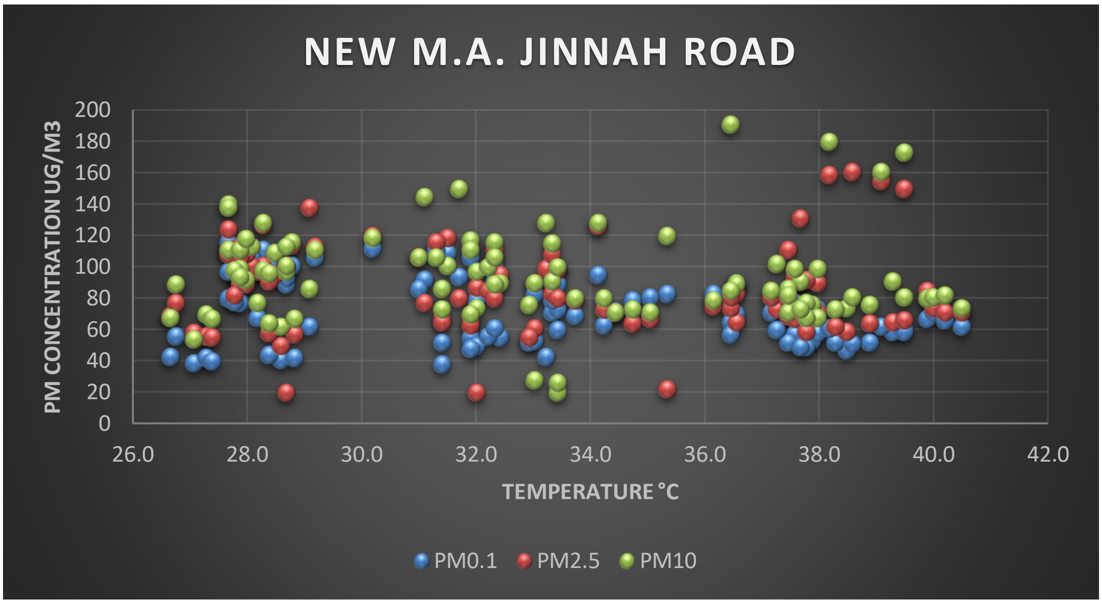

Figure 4.2 PM VS Temperature Graph for New M.A. Jinnah Road

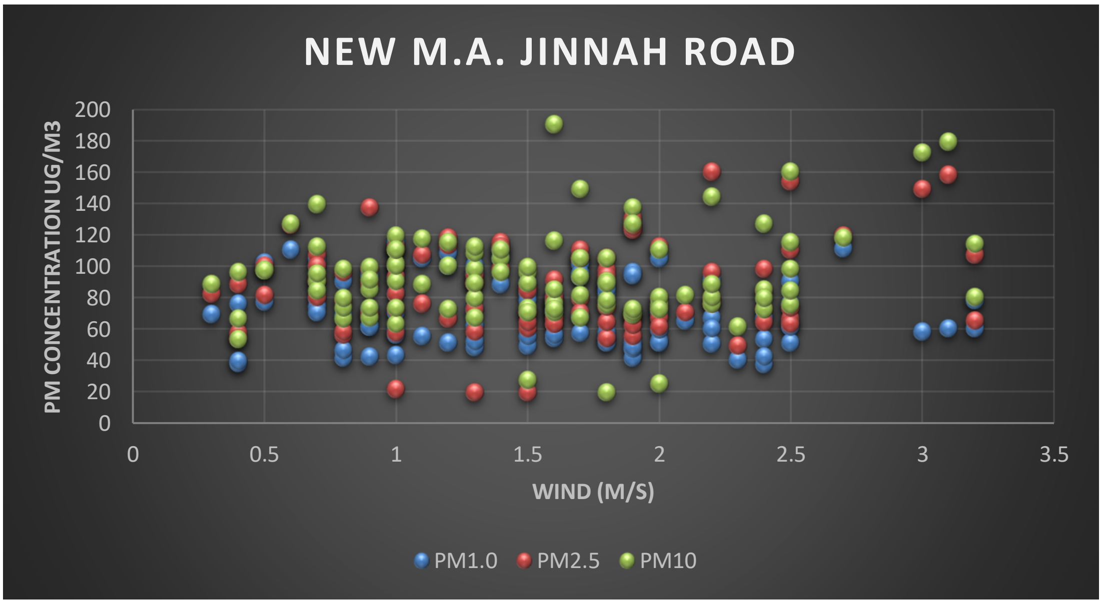

Figure 4.3 PM VS Wind Graph for M.A. Jinnah Road

The coefficient of determination R^2 across all three models of New M.A. Jinnah Road is indicating the percent of how much of the total variance is explained by the independent variable is over 90% on average. In case of New M.A. Jinnah Road the temperature shows a constant inversely varying relation across all three models with respect to PM. In contrast to, temperature, wind and PCE count exhibit a directly proportional relation with PM, except for the Model $PM_{1.0}$ where wind shows a reciprocal relation with PM. The positive coefficients signify a directly proportional relationship, where if the independent variables are increased they cause a positive increment on the dependent variable and vice versa. In this scenario, the negative temperature coefficient represents if the temperature increases the PM will decrease. Similarly, the positive wind and PCE count coefficient denotes if the wind and PCE count increases the PM levels will also go up.

PM Analysis for North Karachi Road:

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM1.0	.942	.887	.874	25.358

Regression Equation:

$\hat{Y}$= - 1.365 (x_1) + 2.534 (x_2) + 0.307 (x_3) For $PM_{1.0}$

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM2.5	.938	.880	.867	32.500

Regression Equation:

$\hat{Y}$= - 2.648 (x_1) + 3.514 (x_2) + 0.443 (x_3) For $PM_{2.5}$

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard Error**
PM10	.941	.887	.874	34.621

Regression Equation:

$\hat{Y}$= - 2.740 (x_1) + 8.927 (x_2) + 0.451 (x_3) For PM_{10}

Where, x_1= Temperature (°C), x_2= Wind (m/s), x_3= PCE Count

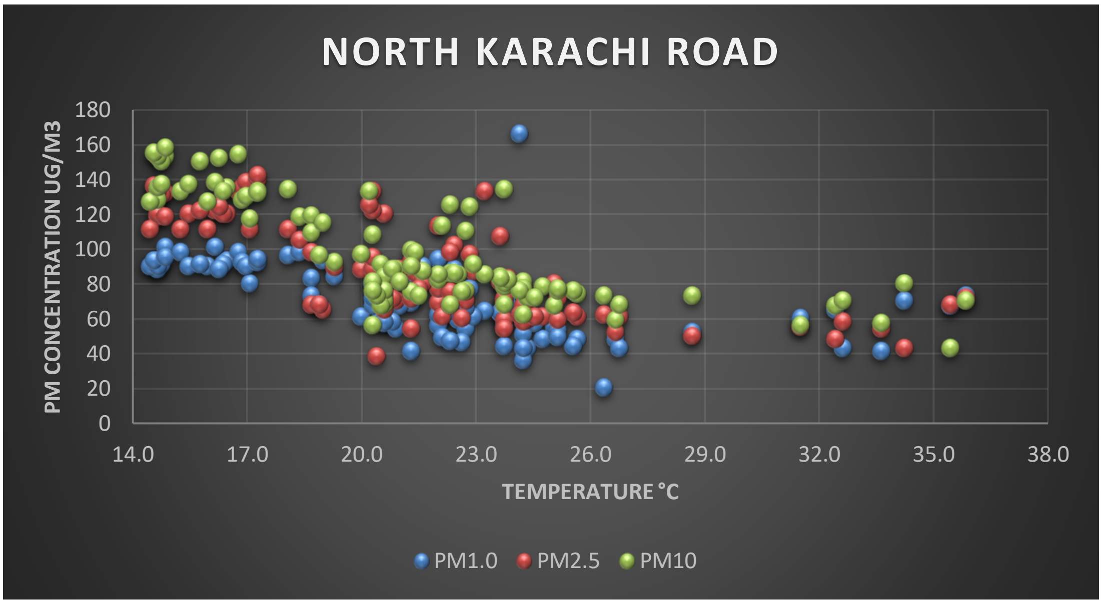

Figure 4.4 PM VS Temperature Graph for North Karachi Road

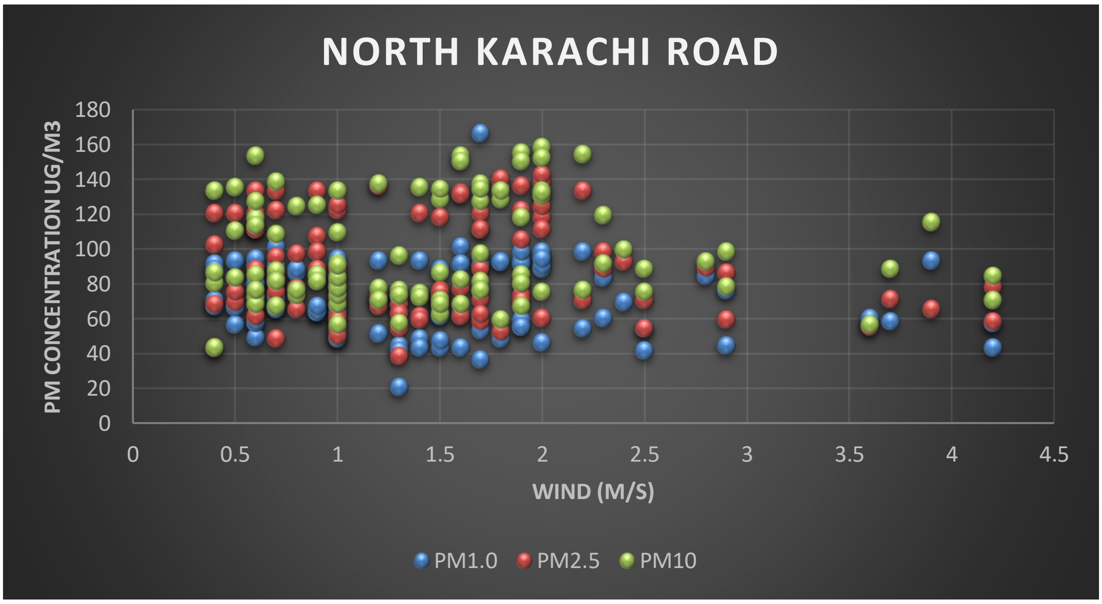

Figure 4.5 PM VS Wind Graph for North Karachi Road

The coefficient of determination R^2 across all three models of North Karachi Road is indicating the percent of how much of the total variance is explained by the independent variable is over 88% on average. In case of North Karachi Road all the independent variables (temperature, wind and PCE count) exhibits a directly proportional relationship across all three models with respect to the dependent variable (PM). The positive coefficients signify a directly proportional relationship, where if the independent variables are increased they cause a positive increment on the dependent variable and vice versa. In this scenario, the positive temperature, wind and PCE count coefficients represents if the temperature, wind and PCE count increases the PM levels will also increase.

PM Analysis for Rashid Minhas Road:

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM1.0	.985	.970	.959	13.603

Regression Equation:

$\hat{Y}$= + 1.313 (x_1) + 7.827 (x_2) + 0.117 (x_3) For $PM_{1.0}$

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM2.5	.980	.962	.950	15.944

Regression Equation:

$\hat{Y}$= + 1.343 (x_1) + 3.630 (x_2) + 0.145 (x_3) For $PM_{2.5}$

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM10	.991	.983	.972	10.438

Regression Equation:

$\hat{Y}$= + 2.194 (x_1) + 2.554 (x_2) + 0.010 (x_3) For PM_{10}

Where, x_1= Temperature (°C), x_2= Wind (m/s), x_3= PCE Count

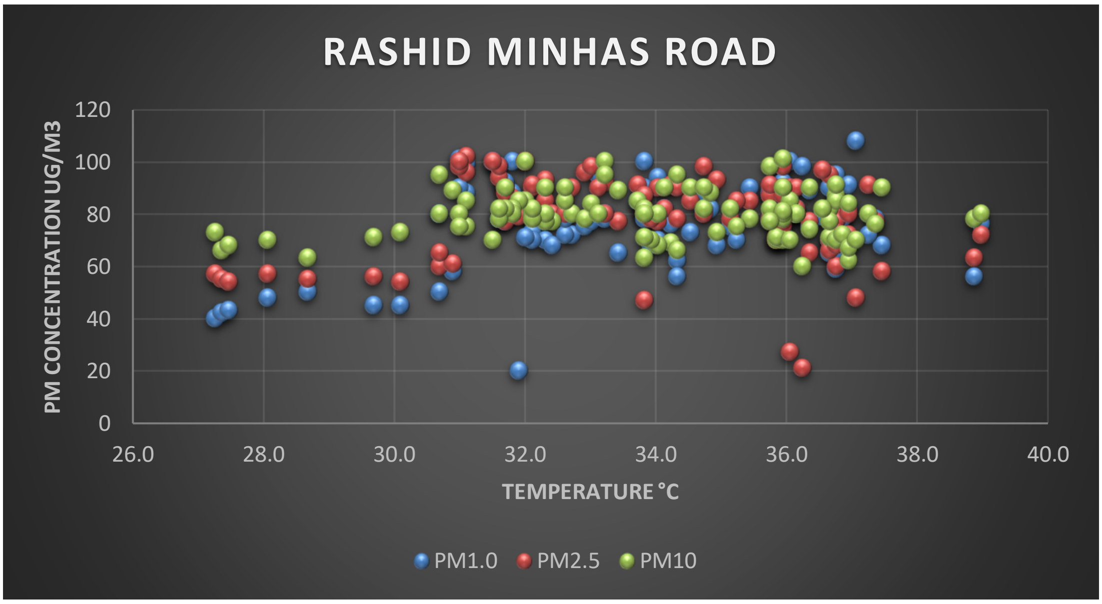

Figure 4.6 PM VS Temperature Graph for Rashid Minhas Road

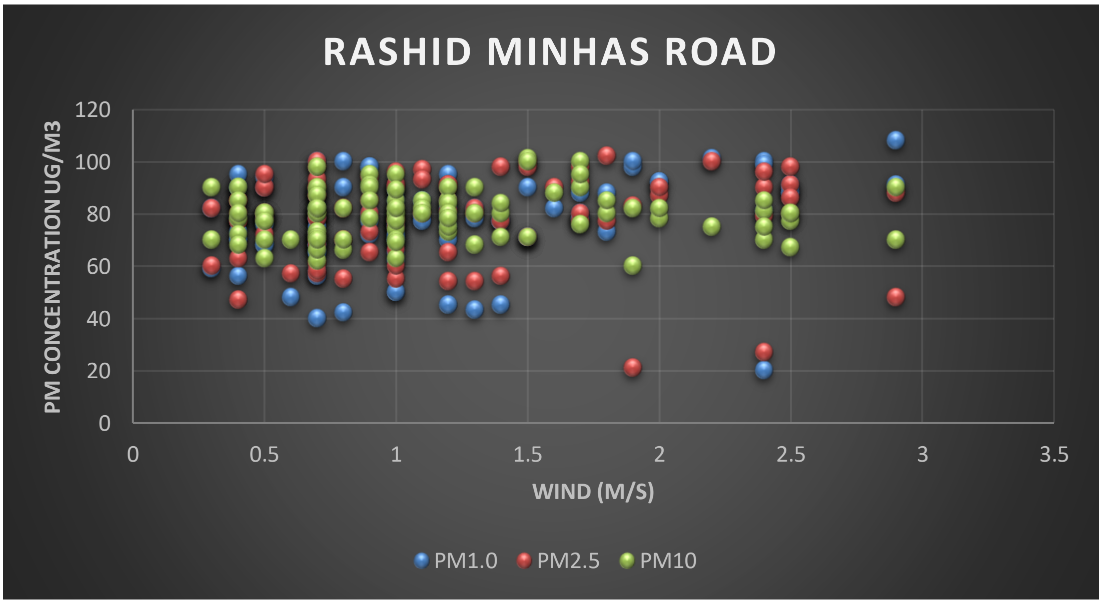

Figure 4.7 PM VS Wind Graph for Rashid Minhas Road

The coefficient of determination R^2 across all three models of Rashid Minhas Road is indicating the percent of how much of the total variance is explained by the independent variable is over 96% on average. In case of Rashid Minhas Road all the independent variables (temperature, wind and PCE count) exhibits a directly proportional relationship across all three models with respect to the dependent variable (PM). The positive coefficients signify a directly proportional relationship, where if the independent variables are increased they cause a positive increment on the dependent variable and vice versa. In this scenario, the positive temperature, wind and PCE count coefficients represents if the temperature, wind and PCE count increases the PM levels will also increase.

PM Analysis for Shahra E Faisal Road:

Model	Multiple R	R^2	Adjusted R^2	Standard
PM1.0	.951	.905	.893	18.175

Regression Equation:

$\hat{Y}$= + 2.782 (x_1) - 10.875 (x_2) - 0.031 (x_3) For $PM_{1.0}$

Model	Multiple R	R^2	Adjusted R^2	Standard
PM2.5	.956	.915	.903	19.875

Regression Equation:

$\hat{Y}$= + 2.979 (x_1) + 10.399 (x_2) - 0.024 (x_3) For $PM_{2.5}$

Model	Multiple R	R^2	Adjusted R^2	Standard
PM10	.957	.917	.904	22.410

Regression Equation:

$\hat{Y}$= + 3.990 (x_1) - 12.186 (x_2) - 0.074 (x_3) For PM_{10}

Where, x_1= Temperature (°C), x_2= Wind (m/s), x_3= PCE Count

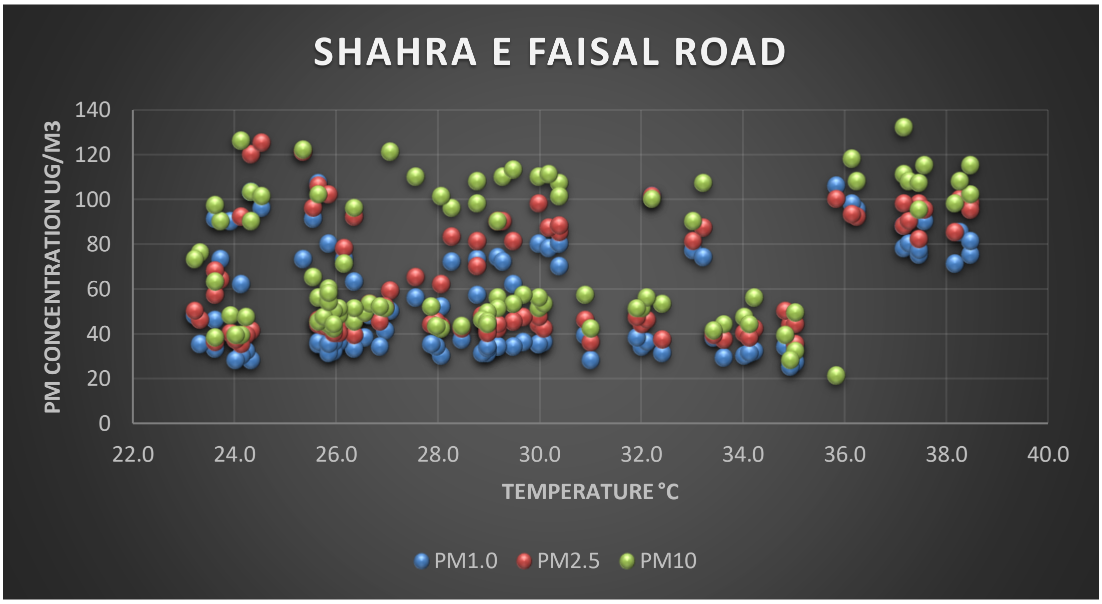

Figure 4.8 PM VS Temperature Graph for Shahra E Faisal Road

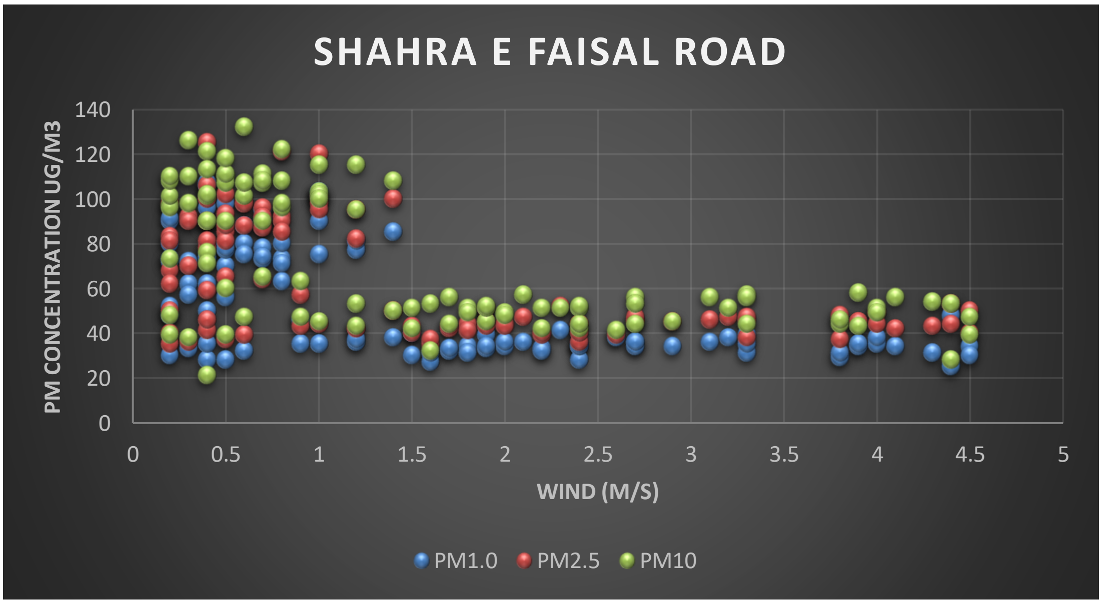

Figure 4.9 PM VS Wind Graph for Shahra E Faisal Road

The coefficient of determination R^2 across all three models of Shahra E Faisal Road is indicating the percent of how much of the total variance is explained by the independent variable is over 91% on average. In case of Shahra E Faisal Road the temperature shows a constant directly proportional relation across all three models with respect to PM. In contrast to, temperature, PCE count exhibit an inversely varying relation with PM across all three models. Meanwhile, wind shows an inversely proportional relation with PM only in Model 2.5. On the other hand, in Model PM1.0 and Model PM10 wind shows a directly proportional relation with PM. The positive coefficients signify a directly proportional relationship, where if the independent variables are increased they cause a positive increment on the dependent variable and vice versa. In this scenario, the negative wind and PCE count coefficients represents if the wind and PCE count decreases the PM will decrease. Similarly, the positive temperature coefficient denotes if the temperature increases the PM levels will also go up.

Complete Statistical Analysis of The Model

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM1.0	.929	.863	.859	26.709

Regression Equation:

$\hat{Y}$= + 1.960 (x_1) - 3.830 (x_2) + 0.048 (x_3) For $PM_{1.0}$

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM2.5	.921	.848	.845	32.527

Regression Equation:

$\hat{Y}$= + 1.925 (x_1) - 1.443 (x_2) + 0.076 (x_3) For $PM_{2.5}$

Model	Multiple R	R^2	Adjusted R^2	Standard Error
PM10	.922	.850	.846	34.788

Regression Equation:

$\hat{Y}$= + 1.926 (x_1) - 1.092 (x_2) + 0.096 (x_3) For PM_{10}

Where, x_1= Temperature (°C), x_2= Wind (m/s), x_3= PCE Count

The main objective of the complete statistical analysis of the model was to understand the behavior of the dependent variable when the independent variables were increased or decreased. The results of the complete statistical analysis are quite consistent across all three models.

The coefficient of determination R^2 across all three models is indicating the percent of how much of the total variance is explained by the independent variable, which is over 85% on average. The positive coefficients signify a directly proportional relationship, where if the independent variables are increased they cause a positive increment on the dependent variable and vice versa.

In this case, the temperature and PCE count; exhibit a directly proportional relation, which is due to the fact that high temperatures can lead to increased emissions of pollutants from sources such as cars and factories. Additionally, warmer temperatures can lead to decreased mixing of the atmosphere, which can trap pollutants near the ground. Moreover, the PCE count is a quantitative measure of vehicles on the road i.e. the greater number of vehicles on the road the greater the PCE count. By increasing the number of vehicles on the road the PM levels will increase.

Meanwhile, wind shows an inversely varying relation with PM, which is due to the fact that wind can help to disperse pollutants by blowing them away from sources of pollution. This can lead to lower PM levels in the immediate area.

4.2.2 Who Air Quality Guidelines

The WHO Air quality guideline’s recommended levels and interim targets for common air pollutants were revised in 2021. The new guidelines are more stringent than the previous guidelines, and they are based on the latest scientific evidence on the health effects of air pollution. A comparison of the air quality guidelines of 2005 with the updated 2021 version can be seen in table 4.2.4.

Table 4.2 WHO Air Quality Guidelines

POLLUTANT	AVERAGING TIME	2005 AQGs	2021 AQGs
$PM_{2.5}$ µg/m^3	Annual	10	5
	24-Hours	25	15
PM_{10} µg/m^3	Annual	20	15
	24-Hours	50	45

4.2.3 PM 24-Hour Mean

This section discusses about the 24-Hour Particulate Matter mean for $PM_{2.5}$ and PM_{10} that was computed on the selected arterials.

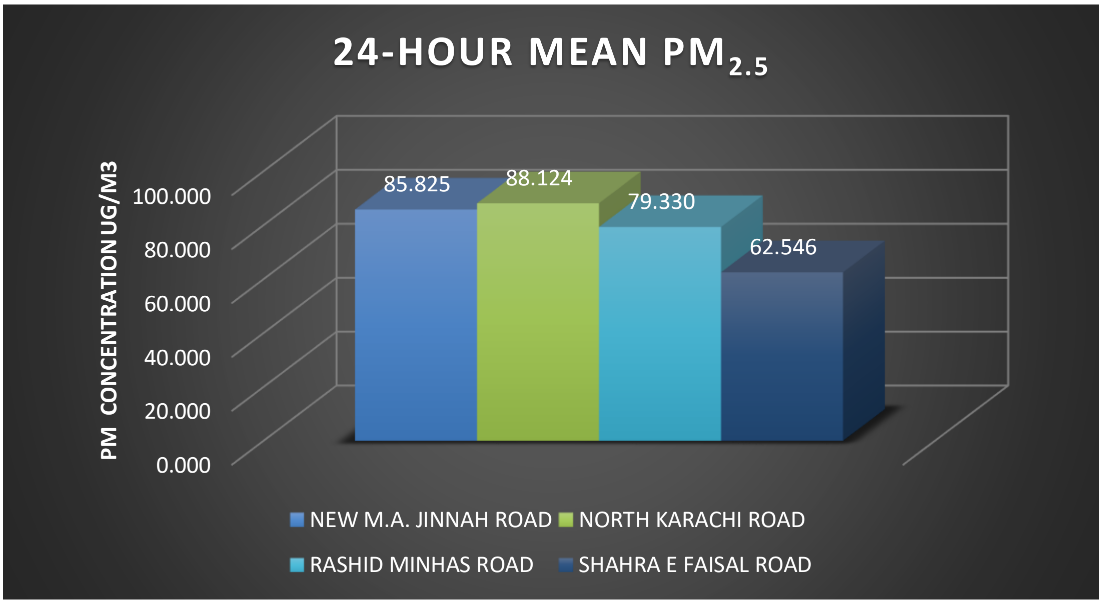

Figure 4.10 24-Hour Mean $PM_{2.5}$

According to the WHO air quality guidelines the 24-hour limit for $PM_{2.5}$ is 15 µg/m^3 as of 2021, but the PM 24-hour mean on every arterial is almost 4-5 times more than the recommended limit, which is an alarming situation for the people who are getting exposed to these high levels of $PM_{2.5}$ on a daily basis.

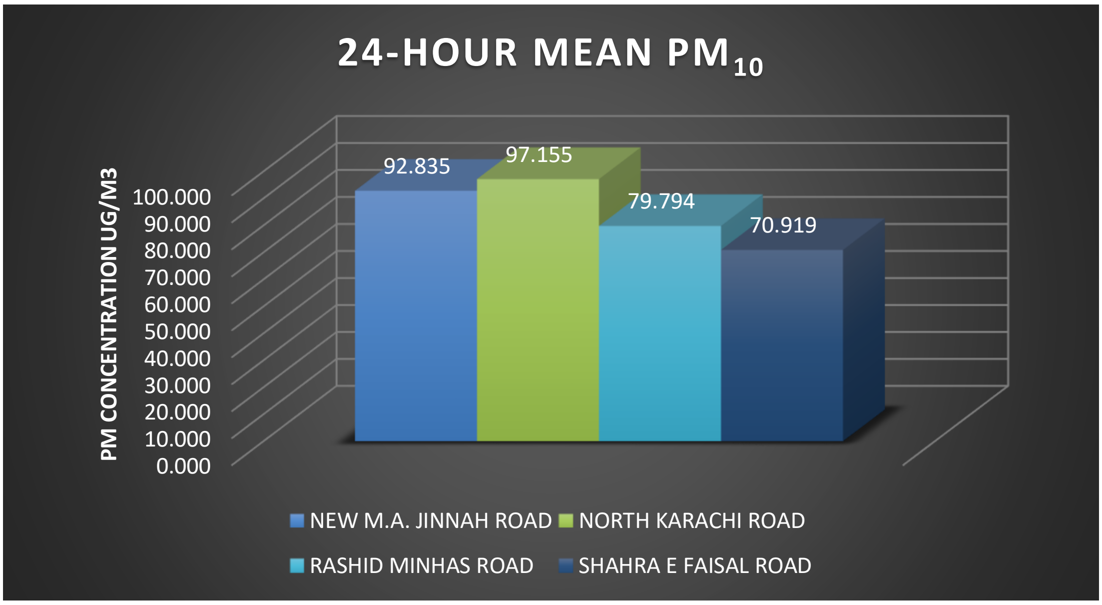

Figure 4.11 24-Hour Mean PM_{10}

According to the WHO air quality guidelines the 24-hour limit for PM_{10} is 45 µg/m^3 as of 2021, but the PM 24-hour mean on every arterial is almost double than the recommended limit, which is an alarming situation for the people who are getting exposed to these high levels of PM_{10} on a daily basis.

The WHO air quality guidelines are recommended levels of air pollution that, if met, would significantly reduce the risk of health problems for people who are getting exposed to these high levels of PM levels.

4.3 Pollution Data Analysis

This section is included to discuss about the major vehicular pollutants that are emitted during the operation of the automobile engine and to visualize the daily trend followed by the above-mentioned pollutants.

4.3.1 Background

Vehicular pollution refers to the release of harmful substances into the environment caused by motor vehicles. These substances, known as pollutants, have negative impacts on human health and the environment. The transportation sector is a significant contributor to air pollution in many countries worldwide, mainly because of the large number of vehicles on the roads. The rise in people's purchasing power has led to increased car ownership, which is detrimental to the environment. In Pakistan, vehicular pollution has been rapidly increasing due to urbanization. The air pollution caused by vehicles in urban areas, especially in major cities like Karachi, has become a critical issue. Symptoms such as coughing, headaches, nausea, eye irritation, respiratory issues, and reduced visibility have started to manifest as a result of vehicle emissions.

The following pollutants make up the majority of the vehicular pollution:

Carbon Monoxide (CO): This invisible and odorless gas is produced through the combustion of fossil fuels like gasoline, with cars and trucks being responsible for almost 66% of its emissions. When breathed in, carbon monoxide (CO) hinders the delivery of oxygen to crucial organs such as the brain and heart. Vulnerable individuals, such as newborns and those with chronic health conditions, are particularly at risk from the impacts of carbon monoxide.

Carbon Dioxide (CO_2): CO_2 is responsible for trapping heat from the sun in the Earth's atmosphere, known as the "greenhouse effect. Motor vehicles primarily produce carbon dioxide (CO_2), which is the main greenhouse gas contributing to this effect.

Nitrogen Oxides (NO_X): Gasoline and diesel engines release a variety of air pollutants, including oxides of nitrogen (NO and NO_2), commonly referred to as NO_X. These nitrogen oxides have detrimental direct impacts on human health and indirect effects on agricultural crops and ecosystems due to the damage they cause. When nitrogen oxides (NO_X) interact with chemicals in the atmosphere, they undergo reactions that result in the formation of secondary fine particulate matter, also known as $PM_{2.5}$ or soot.

Methane (CH_4): Methane is also produced as a result of combustion from motor engines. Methane plays a central role in the generation of ground-level ozone, which is both a dangerous air pollutant and a greenhouse gas. Furthermore, methane is regarded as 20-30 times more powerful as a greenhouse gas in comparison to carbon dioxide (Milich et al., 1999).

Sulphur Dioxide (SO_2): This pollutant is generated by motor vehicles through the combustion of sulfur-containing fuels, particularly diesel. It has the potential to undergo atmospheric reactions, leading to the formation of fine particles that can pose a health hazard to young children and individuals with asthma.

Hydro Carbons (HC): They are the byproducts that can arise from incomplete combustion processes that take place during the operation of internal combustion engines (Flagan et al., 2012). HCs, as pollutants, have the ability to react with nitrogen oxides in the presence of sunlight, resulting in the production of ground-level ozone. This ozone serves as a significant component of smog, and its formation can pose a risk to the respiratory system of humans, potentially causing damage.

4.3.2 Analysis w.r.t Time and Vehicular Pollution on Selected Arterials

The analysis of the exhaust emission with respect to time was conducted for the selected arterials, to visualize the daily trend of various vehicular pollutants. With this aim the traffic volume data was divided in to six vehicles classes depending on their functionality and usage. Additionally, vehicle class data was compared with their respective emission factors, which were obtained by a rigorous review of literature present on the scope of the study.

Table 4.3 Emission Factors for different automobiles in gm/km. (Dutta et al., 2021)

VEHICLE TYPE	CO2	CO	NOX	CH4	SO2	HC
CARS	223.6	1.98	0.2	0.17	0.053	0.25
BIKES	26.95	4.47	0.61	0.18	0.023	1.57
RIKSHAWS	60.3	5.1	1.28	0.18	0.029	0.14
PICKUPS	343.87	3.86	3.89	0.11	1.94	0.54
BUSSES	515.2	3.6	12	0.09	1.42	0.87
TRUCKES	515.2	3.6	6.3	0.09	1.42	0.87

After reviewing the literature, the traffic volume data was compared with the data present in Table 4.3. Subsequently, the entire data was subjected to Normalization.

Normalization refers to the procedure of transforming data to a specific range, such as between 0 and 1 or between -1 and +1. It is necessary to normalize data when there are significant variations in the ranges of different features, as it can be observed in Table 4.3. This scaling technique is particularly helpful when the data set does not include outliers (Ali et al., 2014).

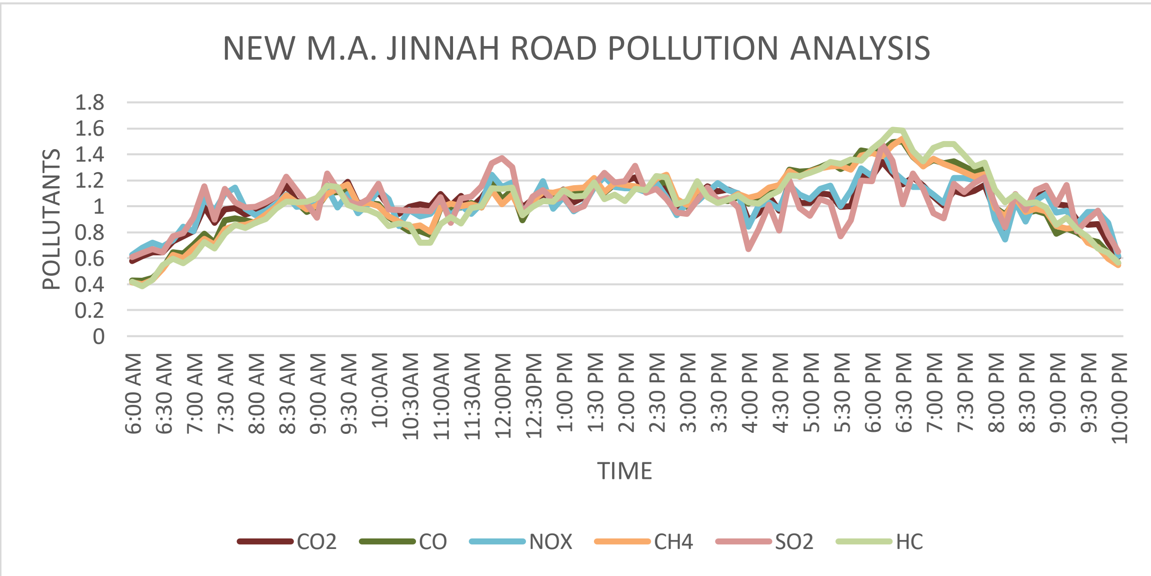

Figure 4.12 Pollution Analysis of New M.A. Jinnah Road

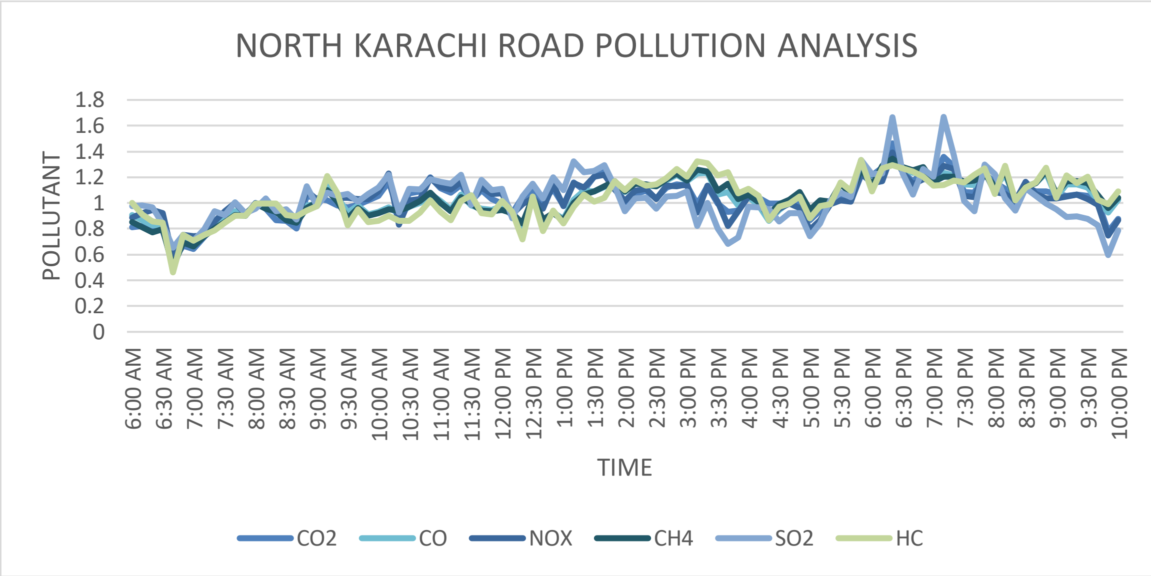

Figure 4.13 Pollution Analysis of North Karachi Road

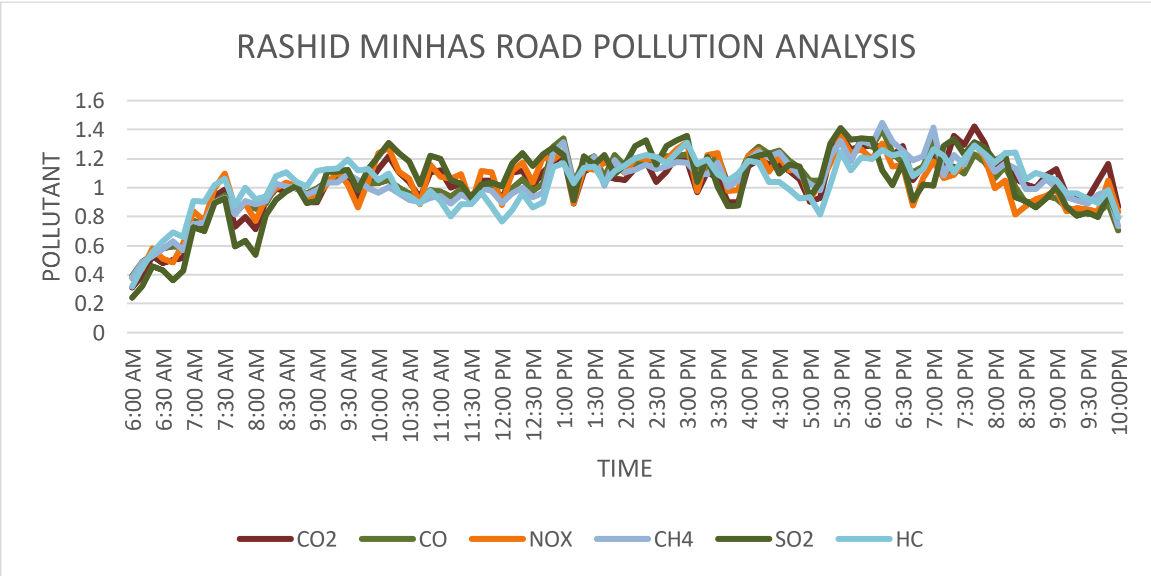

Figure 4.14 Pollution Analysis of Rashid Minhas Road

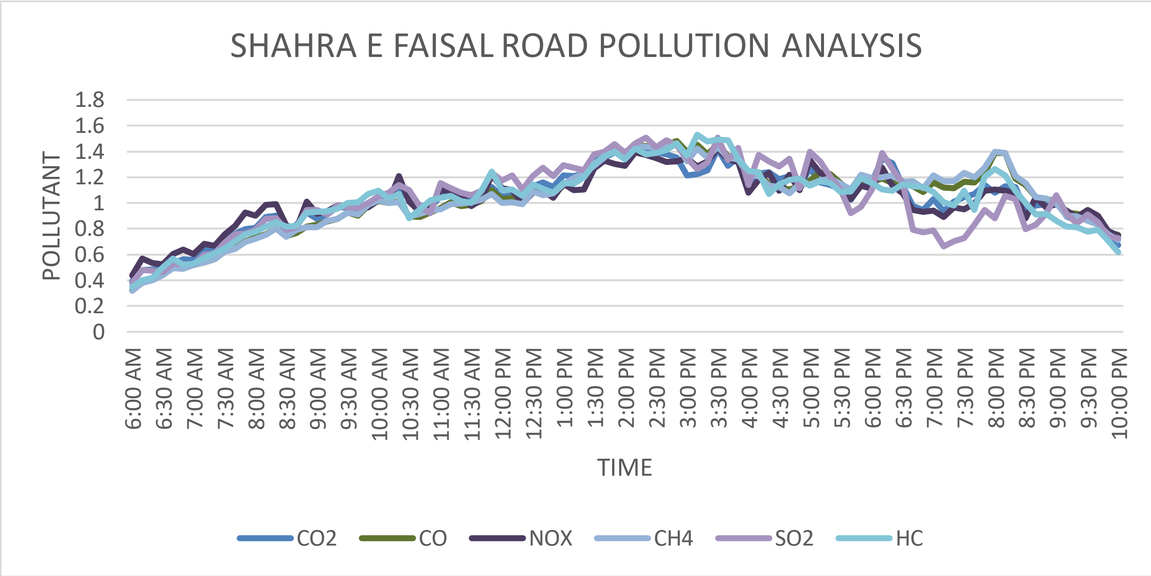

Figure 4.15 Pollution Analysis of Shahra E Faisal Road

From the above-mentioned graphs it can be visualized that the daily trend followed by the vehicular pollutants is in the higher ranges which can cause potential damage to human health and to the environment. The results of this analysis are consistent with the referred literature and the WHO's statistics.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The present study aimed to examine the relationship between particulate matter (PM) and meteorological parameters (temperature and wind) along with the traffic volume and its influence on the rise and fall of PM concentration.

The individual analysis of the collected PM, meteorological parameters and traffic data showed that the particulate matter concentration and temperature exhibited a positive and a negative relation with PM concentration. New M.A. Jinnah Road and North Karachi Road gave a negative temperature coefficient after the multiple regression analysis (MRA). Meanwhile, North Karachi Road and Shahra E Faisal after MRA presented with a positive temperature coefficient. The reason for these contradictions are:

- Temperature can influence chemical reactions in the atmosphere that contribute to the formation or transformation of PM. For example, higher temperatures can promote the formation of secondary organic aerosols, which contribute to PM levels. This phenomenon can result in the increment of PM.
- High humidity and high temperature can result in the decrement of the PM because humid air contain moisture, dry particles absorb the moisture which result in the size increment of PM resulting in the reduced PM levels.

Similarly, after the analysis of particulate matter concentration with wind exhibited a positive and a negative relation with PM concentration. This contradiction is due to the fact that Wind helps disperse PM particles by carrying them away from their source. Higher wind speeds facilitate the scattering of PM over larger areas, reducing local concentrations near emission sources. However, the wind can also carry PM emissions from their source areas and transports them to other regions, potentially affecting air quality in downwind locations.

Moreover, while analyzing the PM concentration to the Passenger Count Equivalent (PCE) also showed a negative as well as a positive coefficient. However, a negative PCE coefficient only occurred on Shahra E Faisal Road, which was due to the fact that wind coefficients for Shahra E Faisal Road were so significant that they affected the PCE count.

The collective MRA of the whole statistical model exhibited a positive relation across all three PM models (PM1, PM2.5 and PM10) with the meteorological parameters and the PCE count. The results are consistent with the results of the referred literature, where temperature, wind and PCE count exhibit a directly proportional relation.

5.2 Recommendations

There are some parameters in the current study that need to be developed in the future to fully understand the PM forecasting process, for instance:

The current research examined the impact of meteorological factors and transportation on the recorded concentrations and size distributions of particulate matter in four main roadways within Karachi city. Throughout the study duration, several significant observations and conclusions were made, which can serve as valuable guidance for future investigations.

Throughout the study, particulate matter (PM) samples were collected for a single day, which introduced a relatively high level of statistical uncertainty to the measurement outcomes. To minimize this uncertainty in the observations, it is recommended to extend the sampling duration and combine the results with those obtained from this study. By doing so, a more accurate and robust understanding of the measurements can be achieved.

In the present research, the measurement of windspeed was limited to surface level only. However, future studies could enhance the understanding of wind patterns by incorporating an anemometer to measure windspeed at higher points. This additional data on windspeed at different levels would provide clearer insights and improve the overall understanding of wind patterns in the area.

During the study, the time interval for taking the temperature, wind speed and traffic volume reading was kept at 10-minutes. This 10-minute interval bracket should be decreased, to obtain a vast dataset. Furthermore, the duration for the data collection on every arterial was 16 hours from 0600hr 2200hr, this 16-hours duration should be increased to better understand the 24-hour PM trend.

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