National College of Business Administration and Economics Lahore

IMPROVEMENT IN ROADSIDE AIR QUALITY THROUGH A SIGNAL FREE CORRIDOR IN LAHORE, PAKISTAN

BY

HAMID MAHMOOD MALHI

MASTER OF PHILOSOPHY
IN
ENVIRONMENTAL MANAGEMENT

NOVEMBER, 2017

NATIONAL COLLEGE OF BUSINESS ADMINISTRATION AND ECONOMICS

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A dissertation submitted to
School of Business Administration

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF PHILOSOPHY
IN
ENVIRONMENTAL MANAGEMENT

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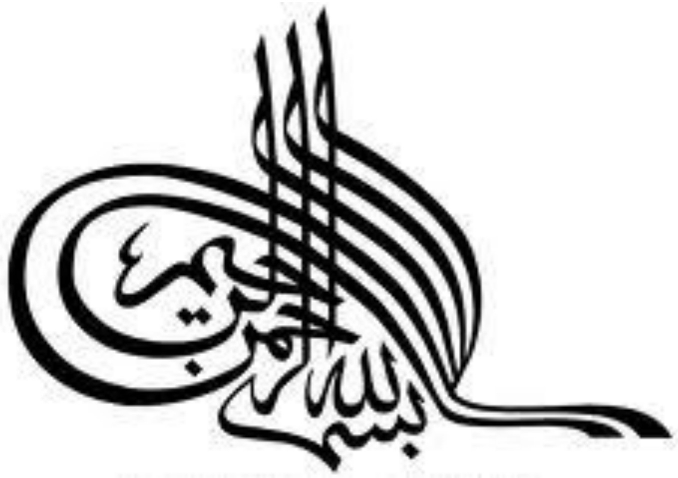

In the name of ALLAH,
The Compassionate,
The Merciful

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<u>Dissertation Committee:</u>

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Chairman

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Member

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Member

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Rector
National College of Business Administration and Economics

DECLARATION

It is to declare that this research work has not been submitted for obtaining similar degree from any other university/college.

HAMID MAHMOOD MALHI
November, 2017

DEDICATION

I dedicate this work

to my parents

whom support and encouragement

always enlightens

each and every perspective

of my life

when things turn gloomy.

ACKNOWLEDGEMENT

Thanks Almighty "ALLAH" Who guides his creatures to know, discover and invent. I had support of a number of people who provided assistance and encouragement in the completion of this research project, which was not less than a daunting task for me.

I owe a debt of gratitude to my highly learned supervisor Prof. Dr. Mahmood Khalid Qamar, whose illustrious advice, intellectual stimulation, encouraging attitude, invaluable suggestions and inspiring attitude which made it very easy for me to undertake this work throughout the course of this research work. During this research, I came to know so many technical points about air pollutants, meteorology, vehicular emission factors, air pollution models, transport sustainability etc.

I also wish to express my gratitude to the Prof. Dr. Irshad Khokher, Head of the Environment Department for her incredible guidance, sustained encouragement, constructive criticism and sympathetic attitude during the period of my research enabled me to technically tackle all the problems during the course of study. I am thankful to Mr. Rizwan Haider from Labour Department, Muhammad Imran from EPA, Dr. Waseem from Transport planning unit, Transport Department for their valuable contributions towards completion to this assignment. Mr. Abdul Hafeez Nasir, CEO and Iftikhar Ahmad, Manager (Operations) of Pak-Green Environmental Lab for facilitation tendered for air monitoring and vehicle counting exercises and their opinions and cooperation.

RESEARCH COMPLETION CERTIFICATE

Certified that the research work contained in this thesis entitled **"Improvement in Roadside Air Quality through a Signal Free Corridor in Lahore, Pakistan"** has been carried out and completed by **Hamid Mahmood Malhi** under my supervision during his **M.Phil. Environmental Management** Programme.

(Dr. Mahmood Khalid Qamar)
SUPERVISOR

ABSTRACT

The research is an effort to carry out comparative analysis of air pollution parameters mainly produced from vehicles, recorded at a road before and after its conversion into a signal free corridor. Moreover, a comparison of air pollution recorded at two selected intersections at a signaled road and two opposite points now converted into signal free points at a signal free corridor. Sophisticated air quality monitoring instruments have been used to monitor the air quality at selected six selected points on the signal free corridor and two points on the parallel signaled road. Number of vehicles using the road have also been counted for 24 hours. Emission factor of vehicles have been calculated with Operational Street Pollution Model (OSPM) on the basis of speed and fuel quality. The reduction in emissions with increase in speed has also been calculated. The city of Lahore has witnessed a high population growth rate in recent years and this increase in vehicle ownership which coupled with conventional transport system produced congestions on roads. A road segment in Lahore stretching from Liberty round about, Gulberg to Qartaba Chowk, Mozang has been converted into a signal free corridor with an aim to reduce traffic congestion on the road and vehicular emissions. Air quality monitoring for 24 hours was carried out at the selected points at signal free corridor for the purpose of its comparison with data recorded in a previous air monitoring study done for the road in the year 2011 before its conversion into a signal free corridor. Moreover, a comparison of AQI of two intersections at a signaled Mall Road with AQI data of opposite points at signal free Jail Road was made for ascertaining the sustainability of a signal free road over a signaled road.

AQI has been improved by 22.2, 13.3, 23.8 and 4.8% on Qartaba Chowk, Shadman Chowk, Fawara Chowk and Liberty roundabout as compared to pre-project conditions. Air quality has been found deteriorated at Liberty roundabout, Canal Road underpasses and PIC during peak hours due to traffic congestion at these points as signal free corridor has invited more traffic. The signal free corridor has benefited to the car users only. The rights of pedestrians and disables have been ignored while designing the road as no footpaths have been provided all along the road and overhead bridges have been erected at quite a distance for crossing over to other side of the road. It is almost impossible for general public to cross the road against the speeding vehicles. Narrow U-turns designs are causing obstructions in smooth flow of traffic at these turns in general and create traffic congestions during peak hours particularly. Improved speed of vehicles has created safety issues for pedestrians, two wheelers and three-wheeler vehicles. Special facilities should be provided also to pedestrians, disables and cyclists.

ABBREVIATIONS

AQI	Air Quality Index
CO	Carbon Monoxide
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
JICA	Japan International Cooperation Agency
NEQS	National Environmental Quality Standards
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
OSPM	Operational Street Pollution Model
PM	Particulate Matter
RH	Relative Humidity
SO_2	Sulfur Dioxide
SUPARCO	Pakistan Space and Upper Atmosphere Research Commission
T	Temperature
THC	Total Hydrocarbons
WHO	World Health Organization
WS	Wind Speed
Pak-EPA	Pakistan environmental Protection Agency
USEP	United States Environment Program
UNFPA	United Nations Population fund

LIST OF TABLES

Table No.	Title	Page
1.1	Trend in Population Growth in Lahore	5
1.2	Trend of Vehicle Population Growth in Lahore	6
3.1	Detail of Air Quality Monitoring Instruments	18
3.2	Criteria of Air Quality based on Air Quality Index	19

LIST OF FIGURES

Figure No.	Title	Page
1.1	History of Extreme Temperatures in Lahore	2
1.2	Trend of Population Growth in Lahore	5
1.3	Trend of Increase of Number of Vehicles from 2010 to 2016	6
3.1	Study Area (Signal Free Corridor)	17
3.2	Location of Signal Free Corridor Lahore Pakistan	17
4.1	Daily Traffic Trend on Different Spots on Jail Road (a) Liberty Rounabout, (b) Fawara Chowk, (c) Shadman Chowk and (d) Qartaba Chowk	22
4.2	Daily Air Pollution Trend at Different Spots of Jail Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}	24
4.3	Comparison of Pollution Level at Canal Crossing at Jail Road and Mall Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}	26
4.4	Comparison of Pollution Level at Zafar Ali Crossing at Jail Road and Mall Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}	28
4.5	Comparison of Previous and Current Studies	30
4.6	AQI at Different Sites Before and After the Project	31
4.7	Calculation of Emission Factor of Vehicles with OSPM at Different Speeds	33

TABLE OF CONTENTS

DECLARATION v
DEDICATION vi
ACKNOWLEDGEMENT vii
RESEARCH COMPLETION CERTIFICATE viii
ABSTRACT ix
ABBREVIATIONS x
LIST OF TABLES xi
LIST OF FIGURES xii

CHAPTER 1: INTRODUCTION 1
1.1. Importance of Clean Air 1
1.2. Urban Air Quality of Pakistan 1
1.3. Air Quality and Meteorology of Lahore 2
1.4. Objectives of the Study 4
1.5. Problem Statement 4
1.6. Significance of the Study 8
1.7. Research Questions 8
1.8. Thesis Outline 8

CHAPTER 2: LITERATURE REVIEW 9
2.1. Concept of Urban Air Pollution and its Health Impacts 9
2.2. Sustainability of Roads 10
2.3. Transport Emissions and Urban Air 11
2.4. Traffic Congestion and Urban Air Pollution 13
2.5. Present Scenario 13

CHAPTER 3: RESEARCH METHODOLOGY 15
3.1. Introduction 15
3.2. The Study Area 16
3.3. Air Quality Analysis 18
3.4. Estimation of Air Quality Index 19

CHAPTER 4: RESULT AND DISCUSSION 20
4.1. Variability in Daily Traffic on Signal Free Corridor 20
4.2. Trend/Variation in Air Pollution 23
4.3. Comparison of AQI of Signal Free Road with AQI of A Signaled Track 25
4.4. Comparison of Air Quality at Canal Crossings 25
4.5. Comparison of Air Quality at Zafar Ali Road Intersections 27
4.6. Comparison of Air Quality Before and After the Project 29
4.7. Calculation of Emission Factors of Different Vehicles 31
4.8. Comparison of Emission Factor of Different Vehicles 31
4.9. Effect of Speed on Emission Factors 32
4.10. Conclusions 34
4.11. Future Recommendations 34

REFERENCES 36

CHAPTER 1

INTRODUCTION

This chapter dilates upon the need and motivation behind the research. The factors behind urban air pollution have been discussed in this chapter. This chapter also explains objectives of the study and significance of the research for sustainability of future traffic management and road development planning, aimed at removing traffic congestion and air pollution on the roads.

1.1. IMPORTANCE OF CLEAN AIR

Life on earth is dependent upon the availability of clean air. The clean air for life support is provided by atmosphere. Importance of the clean ambient air, in the life of a human being is evident from the fact that person breaths 14 to 18 breathings on average in a minute (Fenger, 1999). Different gases form the composition of atmosphere in a very specific proportion. This specific composition guarantees the provision of clean air for breathing to the human being and all living organisms on earth. Any change in this heavenly arranged proportion of these gases may shake up the ecosystem. Any disturbance of the system shall have an impact on the health of all lives dependent on clean air.

1.2. URBAN AIR QUALITY OF PAKISTAN

Air pollution index is high in big cities of Pakistan than many other cities of the developing world (Aziz, 2006). Pakistan is among those developing countries which are pursuing policy of rapid industrialization for achieving its economic growth targets. The industry depends upon engines for running the machines and power plants for generation of electricity. Therefore, industrial processes require huge consumption of fuel. Fuel consumption is major contributor to air pollutants (Rasheed et al., 2014). Almost all goods transport consumes diesel fuel which is a major source of particulate matters emission to the ambient air (Shyamsundar et al., 2001). Air pollution causes economic loss and damage to human health. Economic losses due to environmental impacts are very high in Pakistan and are estimated to the amount of Rs.365 billion annually. Annual economic loss of Rs.65 billion is attributed to the air pollution only (Colbeck et al., 2010). Urbanization in Pakistan is highest among the SAARC countries. Cities in Pakistan are expanding at a great pace. Motorization and energy use has also increased in

Pakistan (Aziz and Bajwa, 2004**)**. Air pollution affects health of its citizens resulting into economic loss (Colbeck et al., 2010). Level of $PM_{2.5}$ in Karachi is the highest (668µg/m^3) amongst top 18 mega cities of the world (Gurjar et al., 2008).

1.3. AIR QUALITY AND METEOROLOGY OF LAHORE

Lahore experiences five distinct climatic seasons. Dry autumn season (16 September – 14 November), Hazy winter season (15 Nov – 15 Feb) with low temperature and inversion effects, spring season (16 Feb – 15 April), summer season (15 April – June) with high temperature and high dispersion effects, rainy monsoon season (July – 16 September) with high temperature, high relative humidity and low pollution due to dispersion and washing effect. The month of June is the hottest month with mean temperature around 33.9 °C. The average temperature of January, the coolest month of the year is 12.8 °C. Mean annual temperature of Lahore is 24.3 °C. Monthly temperature range (variation in temperature) is 21.1 °C. Daily temperature variation is 15.5 °C. The history of extreme temperatures during different months has been given in Fig. 1.1.

Minimum sunshine is available in the month of January which is 6.9 hours per day. The average annual sunshine is 8.4 hours per day (Zaman et al., 2009).

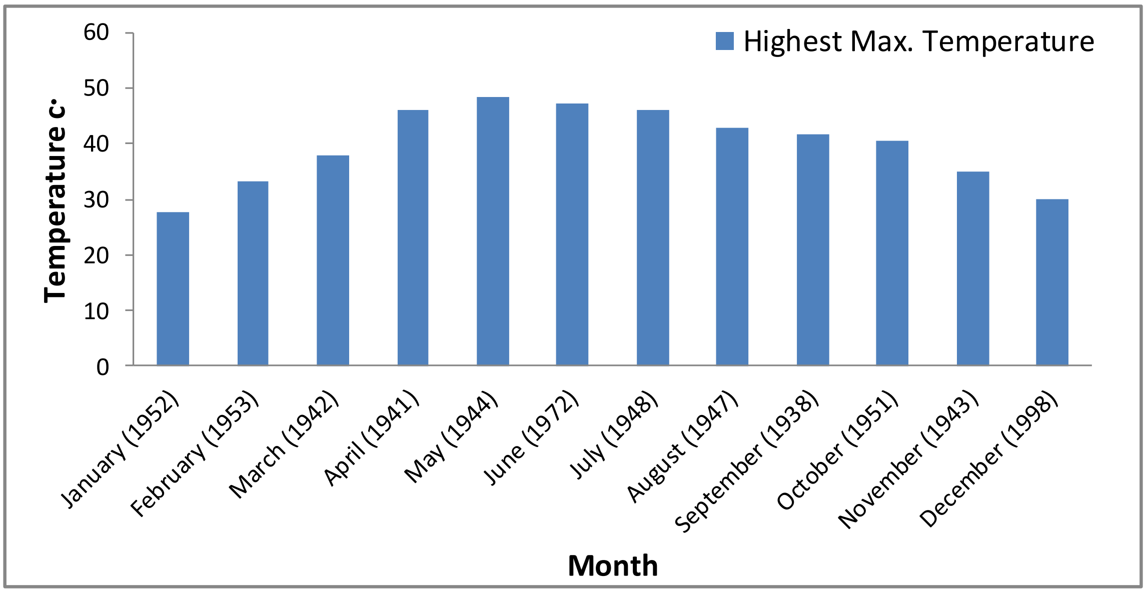

Fig. 1.1: History of Extreme Temperatures in Lahore

The city of Lahore has witnessed an enormous expansion in size and population over the years. Lahore is not only the second largest city of Pakistan but it is also fifth largest city of South Asia and twenty third largest city of the World (Rasheed et al., 2015). The environmental pollution produced through high energy use, increased vehicular use and industrial activity is a rapidly growing threat in Lahore. The ambient air quality data shows that carbon monoxide level here exceeds World Health Organization's recommended levels (Naqvi, 2015). Biswas in his research pointed out that quantity of $PM_{2.5}$ in the air was much more in Lahore than in Seoul, New York City and Hong Kong (Raja et al., 2010). According to PAK-EPA and JICA concentrations of NO_X and PM_{10} in the air of Lahore are higher than WHO standards for these concentrations (Pak-EPA and JICA, 2000).

Air pollution in Lahore is worse after Karachi and level of $PM_{2.5}$ is 14 times higher than levels prescribed in USEP standards (Lodhi et al., 2009). Annual trends point out that air quality of Lahore city is deteriorating. Ambient air contains higher amount of TSP, PM_{10}, $PM_{2.5}$ and hydrocarbons in Lahore than other cities of Pakistan (Ghauri et al., 2007). Transport, industries and fossil fuels used in thermal power plants are major contributors to the air emissions in Lahore and Karachi (Parekh et al., 1989). Pakistan Space and Upper Atmosphere Research Commission frequently monitor air quality in the country. A short study in this regard was conducted during winter of year 2005-2006. According to this study very high concentration of SO_2 was found in the air during foggy days (Biswas et al., 2008). Data collected from air quality monitoring station established at Town Hall, Lahore for the year 2010 shows that inhalable particle ($PM_{2.5}$) was almost five times above the National Environmental Quality Standard (NEQS) and Oxides of nitrogen were recorded at twice the level of NEQS level.

The road infrastructure of Lahore is being upgraded to manage the ever-increasing traffic and avoid environmental degradation, most significantly air pollution. Until now, no study has been conducted as a follow up evaluation of environmental impact by air pollution index of a major road infrastructure development project after its completion. It has become imperative upon the city planners to take such policy measures which remove congestion from urban roads and bring economic health to the city and physical health to the people of the city. Urban planners should incorporate health as a corner stone while planning any physical infrastructure.

1.4. OBJECTIVES OF THE STUDY

The research is based upon comparative analysis of values of air pollutants mainly generated from vehicles, monitored at signal free corridor before and after its conversion into a signal free corridor. Furthermore, a comparison of air pollutants monitored at selected signaled intersections at a signaled road and opposite intersections now converted into signal free intersections at a signal free corridor. The results obtained shall also explain traffic congestion impact on the air quality of the study area. The stated aims of the study can be expressed as

1. Monitoring of nitrogen dioxide, carbon monoxide, Sulfur dioxide and particulate matter (PM) pollutants on the selected sites and comparison with baseline data recorded in EIA report prepared for the project and NEQS/PEQS (2016).
2. Comparison of emissions monitored at Signaled intersections of Mall Road and opposite intersections now converted into signal free intersections on Jail Road for determination of variation in air quality of these selected locations
3. Determination of air quality for four different selected sites at Signal free corridor.
4. Comparison of air quality parameters of these four points monitored before and after its conversion into signal free corridor.

1.5. PROBLEM STATEMENT

Rapid urbanization along with population growth places more stress on existing roads of the cities (UNFPA, 2015). Air pollution increases with more vehicles on these roads. The roads are redesigned and widened to accommodate this increased pool of vehicles. Therefore, all features of environmental impact assessment should be included into the design of every new urban road infrastructure development project. Reduction in air pollution levels in cities and countries can help reduce incidences of different disease like stroke, heart disease, lung cancer, and respiratory diseases including asthma (WHO, 2016). Urban Governments around the world imply various technologies, investment strategies and policy options aimed at reduction of air pollutants. Such strategies may involve instruments of spatial planning and transport planning. The strategy of planning infrastructures for smooth flow of transport also reduces long-lived CO_2 which damages good health. Therefore, it is need of the hour to take early action to reduce air pollution in cities to save lives. Lahore is the second largest city of Pakistan and is the largest city and capital of Punjab Province. The population of Lahore is 11.1 million (Bureau of Statistics, 2017). Air quality is posing serious threat to public health in many parts of Lahore. This threat is likely to increase in coming days. World Health Organization has warned that human health is at stake at the hands of air pollution (WHO, 2016). Trend of population growth from 1951 to 2017 has been given in Table 1.1. Trend of population growth has also been shown in Fig. 1.2.

Table 1.1
Trend in Population Growth in Lahore

Year	**1951**	**1961**	**1972**	**1981**	**1998**	**2017**
Population (Million)	0.86	1.32	2.2	2.99	5.21	11.1
Annual Growth Rate		5.35	6.06	3.99	4.12	5.95
% Change Overtime		53.49	66.67	35.91	74.25	113.05

Source: Pakistan Bureau of Statistics

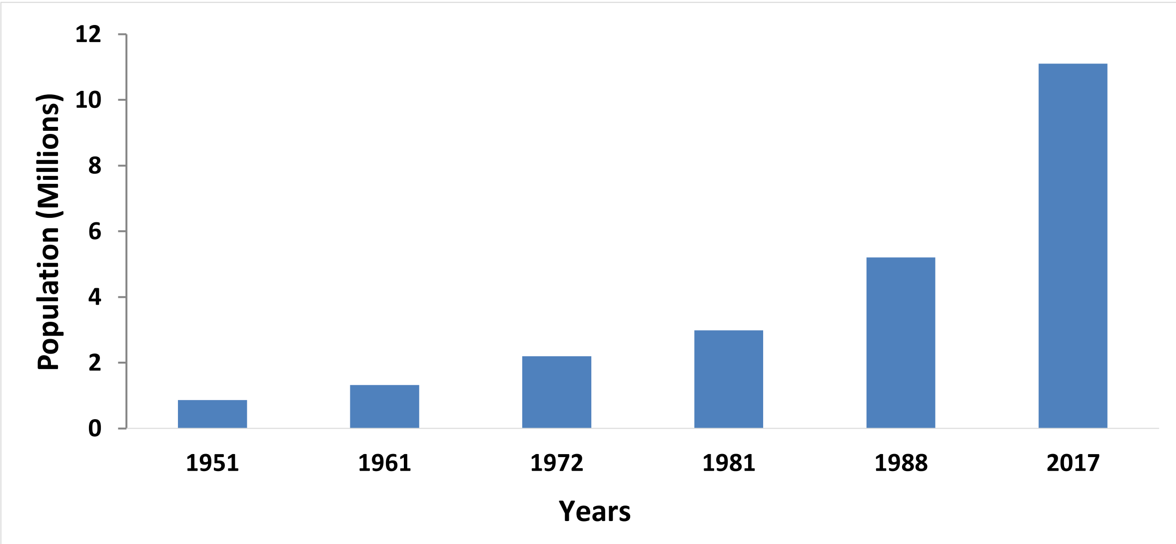

Fig. 1.2: Trend of Population Growth in Lahore
(Source: Pakistan Bureau of Statistics)

There are 5.5 million registered vehicles in district Lahore as per Excise and taxation Department, Government of the Punjab (Bureau of Statistics, 2016). The rate of growth of vehicular population in Lahore from 2010 to 2016 is given I Table 1.2. The trend of increase of vehicular population from 2010 to 30th, June 2016 has been shown in Fig. 1.3. There are old as well as new model of vehicles in Lahore. Poor fuel quality and less expert mechanics results in poor engine efficiencies of vehicles.

Table 1.2
Trend of Vehicle Population Growth in Lahore

Year	2010	2011	2012	2013	2014	2015	2016
Total Vehicles (Million)	2.4	2.7	3.0	3.4	4.0	4.7	5.5
Rate of growth (%)	----	11.16	11.06	10.89	15.04	15.07	14.55

Source: Pakistan Bureau of Statistics

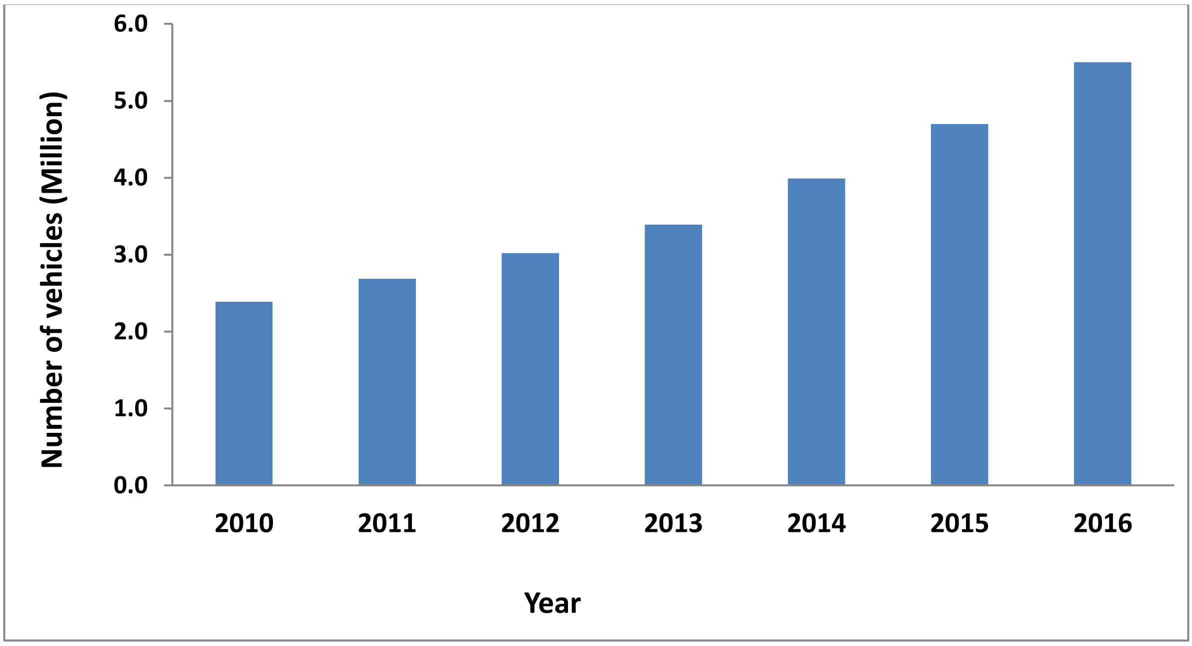

Fig. 1.3: Trend of Increase of Number of Vehicles from 2010 to 2016
(Source: Pakistan Bureau of Statistics)

Increased number of vehicles produces congestion on roads. Various governments around the world applied numerous solutions aimed at removing traffic congestion on the roads. A number of countries implemented policy of congestion charging scheme. Another option available with the policy makers has always been the building of new roads and expanding existing road network to reduce traffic congestion and reap the benefit of improved air quality. Lahore expanded exponentially in recent past and major road arteries of the city came under sever traffic pressure. The Gulberg and surrounding area saw a phenomenal commercial activity since last one decade. The vehicular volume increased many fold causing traffic congestions on Main Boulevard, Gulberg and adjoining Jail Road. The vehicular increase also caused congestion on the roads and adjoining business centers. The Lahore Development Authority, Lahore decided to redesign the road from Liberty round about, Gulberg to Qartaba Chowk, Jail Road to ease the flow of traffic with stated benefits of air quality improvement through reduced vehicular emissions.

Lahore is geographically located in the industrial cluster of Pakistan and it is adjacent to the Indian Industrial zone (Rattigan, 2002). Lahore is considered as the second most polluted city of Pakistan after Karachi and pollution is mainly caused by transport in Lahore (Ali & Athar, 2010). Increased traffic demand destroys the smooth flowing traffic conditions and congestion is caused resultantly (Smith et al., 2008). Although there are some industries and settlements that cause of some amounts of pollutants but roads are found to be major source of pollution in Lahore. The Government is planning further urban development and improving existing urban infrastructure entailing environmental consequences for urban dwellers and the natural environment.

The Gulberg area of Lahore has become commercial hub of the city. The main boulevard of the area saw a phenomenal rise in traffic volume causing congestions and slow mobility which had adverse impacts on air pollution produced from vehicular emissions. Traffic Engineering and Planning Agency, Lahore recommended that urban road from Qartaba Chowk to Fawara Chowk in Gulberg to Liberty Market Roundabout may be converted into a Signal free corridor to facilitate the commuters so that they will get rid of long queues and traffic jams. Long queues and traffic jams result in high burning of fuel which causes high vehicular emission, hence improving the air quality of the area (EPA, 2015). As this project has been completed now, it is right time to take stock of air quality parameters to review the targets set by the proponent agency regarding environmental assessment made at the time of planning the project. Several studies have been performed on the measurement of air pollutants on different roads of in urban polluted regions as part of EIA for undertaking construction, rehabilitation or infrastructure improvement project but no study has been carried out to monitor the projected parameters after the completion of that project and further no study has been done comparing the pollutants measured at signaled road and signal free road especially in Lahore.

Monitoring of air quality is carried out by government, private institutes and individual researchers but environmental evaluation after road infrastructure development intervention is not regularly done for the purpose of future infrastructure projects planning and design regarding its impact on air quality of the city. Various studies valuated the environmental impact of vehicular emissions at a specific road and response of roadside plants but no follow up environmental evaluation of a road improvement project aimed at improving traffic resulting in low vehicular emissions after the completion has been conducted in Lahore. Therefore, it is important to take post project completion stock of the vehicular emissions comparing with pre- project completion air pollution parameters and with the parameters of a parallel signaled road for future urban road infrastructure planning and environmental sustainability of signal free corridor road over signaled road. This study will be helpful in future for policy making regarding road construction, traffic management and air pollution mitigation.

1.6. SIGNIFICANCE OF THE STUDY

Urban environment is under extreme pressure due to rapid urbanization in Pakistan. The present rate of urbanization tells that this environment will come under more pressure in coming years. Threat to environment in urban areas will make lives of urban dwellers unhealthy. The study would be helpful to calculate the environmental and social contribution of the signal free corridor.

1.7. RESEARCH QUESTIONS

1. What is the measurement of air pollutants, Nitrogen Dioxide, Sulphur Dioxide, Carbon Monoxide and Particulate Matter at selected locations of the signal free road and at selected locations of signaled Mall Road?

2. What is the difference among these air quality parameters measured at different locations of signal free corridor and signaled Mall Road?

3. Has this infrastructure development project of conversion of an urban road into a signal free corridor helped improve the urban air quality?

1.8. THESIS OUTLINE

Monitoring of air pollution is conducted for determination of environmental impact by air pollution index of converting a signaled road into a signal free corridor for the purpose of removing congestions. This thesis is composed of four chapters, references and appendices. Introduction of the thesis is described in the First Chapter and Second Chapter contains Literature review which is research conducted by other researchers about this research area. Third Chapter is about Methodology applied for conducting this research. The last Chapter explains about data collection and subsequent analysis done, results obtained and discussion related to the results. Conclusion of the research is added at the end of this Chapter with some recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1. CONCEPT OF URBAN AIR POLLUTION AND ITS HEALTH IMPACTS

The natural environment remained almost undisturbed till the dawn of Industrial revolution in Sixteenth Century when industries started consumption large amount of fuel. These industries began to emit dangerous gases and chemicals to the atmosphere. The Cities grew large and traffic increased phenomenally adding harmful gases and chemicals contaminating the urban environment by polluting the air (Omer, 2009).

It is a matter of great concern that there are many cities in the World where the levels of air pollution are 10 times higher than threshold levels given in world health organization guidelines. Urban centers are faced with environmental concern of continuous air quality degradation (Gwilliam et al., 2004). Most of the air pollution which occurs in urban areas is due to vehicles (Stone et al., 2010). Air pollutants are comprised of both particulate matter (PM) and gaseous pollutants which may cause adverse health effects on humans, affect plant life, and impact the global environment by changing the atmosphere of the earth (Royal Commission on Environmental Pollution, 2007). Air pollution is a serious problem in many cities of developing countries. Ambient concentrations of fine particulate matter, which is one of the most damaging air pollutants are often several times higher in developing country cities compared to the cities of industrial countries. Ambient CO concentrations can be high at certain “hotspots” such as traffic corridors and intersections. The largest human and economic impacts of air pollution are the increased incidence of illness and premature deaths (WHO, 2015). Using damage to human health as the primary indicator of the seriousness of air pollution, the most important urban air pollutants to be controlled in developing countries are lead, fine particulate matter and in some cities ozone. Air pollution impact in developing countries often fall disproportionately on the poor, compounding the effects of other environmental problems, such as the lack of clean water sanitation (Brunekreef et al., 2002). Climate change is taking place due to greenhouse gas emissions from fossil fuel consumption. The transport activities are a major contributor to urban air pollution problem. Majority of greenhouse gas emissions are generated by the urban centers because half of the world population lives in cities. The urban share of global greenhouse gas emissions is between 30% and 40% (Dodman 2009) and according to another definition it's up to 75% or 80% (Satterthwaite 2008). The economic wheel of developing world cities is fast catching up with first world cities, bringing emissions of greenhouse gases up also.

Annual per capita CO_2 emissions have risen from 3.8 tons in 1985 to 16.7 tons in 2006 in case of Shanghai (Dhakal, 2009). The cities of developing countries have already been found emitting more greenhouse gases than cities of developed world. The per capita emissions from Shanghai and Bangkok (10.7t) or Cape Town, South Africa (11.6t) are more than Geneva, Switzerland (7.8t), Prague, Czech Republic (9.4t) and London, United Kingdom (9.6t) (Kennedy et al. 2009).

2.2. SUSTAINABILITY OF ROADS

Green economy has become a buzzword since year 2012 when World nations gathered at Rio de Janeiro, Brazil for UN Conference on Sustainable Development (UNCSD), commonly known as Rio+20. The agenda was to preserve the natural environment while carrying out economic boost activities for improving living standards of the people. This was referred as "green economy". The green economy is a development model which hinges upon the principles of sustainable development and understanding of ecological economics (Brand, 2012). Road infrastructure development is the major sector in any developing economy around the world. Construction and operation of roads has been focus of green economy activists due to its environmental implications. Road infrastructure impacts the environment during its construction, operation, maintenance (Stripple, 2001). The world is more concerned these days about sustainability of road infrastructure development (Soderlund, 2008). Various studies have mentioned that infrastructure sustainability is composed of three aspects-environment, social wellbeing and economy (Shaw et al., 2012). The world is paying increased attention towards environmental dimensions of infrastructure development schemes in the wake of likely global warming threat. Different countries of the world have already adopted the concept of "green roads" and successfully initiated the road sustainability assessment schemes like Invest (Australia), AGIC (Australia), Greenalites (USA), Green roads (USA), Envision (USA) and CEEQUAL (UK). All these schemes were designed to assess the three green infrastructure sustainability aspects (Shaw et al., 2012). A significant use of land, energy and resource consumption is involved in road infrastructure development projects which causes remarkable impact on environment and surrounding community. Furthermore, road design including road geometry, pavement structure and surface conditions affects the traffic congestion, fuel consumption patterns resulting into emissions (Lepert and Brillet, 2009). Although emissions, air quality, water quality, biodiversity, habitat and species protection, pollution, landscape and aesthetics are conventional "environmental factors" but now the impacts on communities, resource utilization efficiency, materials type, waste management and futuristic predictions on sustainability are also considered part and parcel of environmental factors (Griffiths, 2008). The conventional environmental assessment studies often ignored these factors but recent studies have mentioned the importance of a comprehensive environmental assessments including sustainability of roads as an important component of environmental indicators (Santero et al., 2011). Modern day planners are compulsorily including sustainability factor into planning and designing, construction and operation of the roads (Muench, 2010).

"Agenda 21" of 1992 UN Conference on Environment and Development (UNCED) mentioned the importance of road construction and operation sustainability and defined "S*ustainable construction as a comprehensive cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructures, until their final deconstruction and management of the resultant waste"* (p. 6).

Any decision made by local authorities and provincial authorities related to transport infrastructure lasts for decades and it shall have long lasting impacts on urban development as well as urban air quality. Every new built structure and infrastructure in urban areas may cause consumption of huge amount of energy generating air pollution for coming generations. If these investments are made prudently, keeping in view the air quality impacts of the said investment would bring climate benefits for decades (Sovacool and Brown, 2010).

2.3. TRANSPORT EMISSIONS AND URBAN AIR

Road transport is a major source of urban air pollution and vehicles are responsible for 65% of air pollution in Lahore. Two-thirds of Particulate Matter, 50% of NO_X, 70% of CO and 50% of hydrocarbons are released to air by transport and energy sectors. The most damaging air pollutant is PM.

Weng and Yang (2006) believe that rapid urbanization and automobile exhaust are major contributors of pollution in metropolitans. Fossil fuel burning, incineration of solid waste, indoor pollution and dust are major man-made sources of pollution (USEP, 2011). Pollution is caused by the release of toxins from homes or domestic incineration while major sources are industrial waste and automobile (B.Ostro, 2004). According to Zhang et al. (2008) traffic pollution is the predominant source of PM_{10} Carbonaceous Aerosols Traffic problems of all urban centers are manifested in traffic congestion, road accidents, unauthorized parking of vehicles, bad decisions of land use, improper transport planning coupled with worst road networks.

Emission factors related to the sulfur and benzene are dependent upon their respective concentrations in fuels, it is important to improve the quality of fuel for low emissions of sulfur and benzene. Improving engine design technology along with installation of catalytic converters the emission factors of NOx, PM and CO can be improved. Traffic emitted pollutants damage buildings, the natural environment and human health, reducing life expectancy. Infrastructure and urban Development Department of the World Bank way back in 1990 mentioned that automotive air pollution will intensify with increasing urbanization and the rapid pace of motorization in developing countries. Without effective measures to curb air pollution, some 300-400 million city dwellers in developing countries will become exposed to unhealthy and dangerous levels of air pollution by the end of the century (Faiz and De Larderel, 1993). Studies found that air pollution causes mortality and hospital admissions for treatment of respiratory and cardiovascular diseases. About 6% of deaths per year in Europe are due to air pollution. Half of the deaths caused by air pollution are attributed to vehicular traffic emissions. Traffic related emissions are cause of 25000 cases of bronchitis in adults, 290000 children are reported to fall ill to bronchitis, 0.5 million asthma attacks occur due to vehicular exhaust emissions and it bars 16 million persons days from carrying out their daily routine activities (Kunzli et al., 2000).

Fuel use has been increasing in Pakistan at a rate of 6% per annum. Fifty per cent of all petroleum products are consumed by transport vehicles in Pakistan. Many neighboring countries in the region successfully decreased the sulfur content is diesel to 0.035% and in furnace oil to the level of 0.5% (Martin et al., 2006) which resulted into reduction in certain air pollutants (Mofijuret et al., 2016).

Many studies have been performed to monitor the vehicular emissions in urban areas and their environmental impacts especially in the backdrop of global concern of climate change. Urban areas where transport activities are major contributor to air pollution, it is important to determine in what ways these activities can be reduced (Lal et al., 2016). Administratively simple policies that encourage clean fuels and better traffic management are the most promising approach to control vehicle pollutant emissions in developing countries.

2.4. TRAFFIC CONGESTION AND URBAN AIR POLLUTION

Population of Lahore has increased very rapidly in recent past and it stands at 14 times of population of the first census in 1951. The period between 1972 and 1981 saw a phenomenal rise in population growth rate, i.e., 4.3% per annum. The rapid urbanization and increased vehicle ownership resulted into an increased travel demand. The demand for transport is overwhelming during peak hours in the urban areas, resulting into congestions on roads. Frequent traffic congestions in urban areas has forced many Governments to levy congestion charges on cars to convince motorists to keep their cars off the road from certain areas (Beevers and Carslaw, 2005). As this increased number in vehicles during peak hours consumes more fuel on average it causes a huge amount of vehicle related exhaust emissions. These emissions also include greenhouse gases and other dangerous air pollutants and this emission problem is further aggravated by low acceleration and stop and goes nature of movement of vehicles (Olszewski, 1993). Increased emissions are the consequence of stop and go traffic conditions attached with congestion. Congestion produces increased acceleration and deceleration phenomenon by vehicles resulting into more emissions (Barth and Boriboonsomsin, 2008). When road traffic emission is estimated, the major factor taken into consideration is congestion along with vehicle speed and vehicle category (De Haan and Keller, 2000). Many researchers performed studies on the issue of traffic flow in urban areas. Traffic flow at urban un-signaled intersections was studied by (Ruskin and Wang, 2002). (Kidwai et al., 2005) studied traffic flow at signaled intersections at Kuala Lumpur, Malaysia.

2.5. PRESENT SCENARIO

The roads of Lahore witness frequent congestions especially during peak hours. Congestion causes two problems. Time cost of a vehicle per kilometer goes up during congestion because with addition of more vehicles to the already crowded road network system, travel time increases for all transport aboard passengers. Secondly vehicles move at lower speed which becomes much slower than average routine speed. The stop and go movement of vehicles leads to increase in rate of emissions per kilometer. These two problems are correlated with each other (Johnson, 1997). The vehicular emissions of CO increase hundred per cent with decrease in speed from 40 km/hour to 20 km/hour (Krawack, 1993). So, making the vehicles run smoothly not only help avoid air quality degradation but also saves billions of rupees in terms of evading excess travel time required and gasoline to be consumed.

The world has awakened to find the solution of impending danger of Global Warming and Climate change. Transport sector is often ignored while devising an emissions mitigation action plan to avoid climate change; focus is always on energy and industrial activities as major contributors to greenhouse gas emissions.

Although many researchers discussed environmental problems caused by traffic delays at busy road intersections but no ideal model for solving traffic congestion in urban areas has yet been developed for implementation on ever expanding urban roads of developing countries. Therefore, development of transport infrastructure lagged well behind the travel demand increase and caused transport related problems like traffic congestion, poor environment (JICA, 2012).

Therefore, it is all the important to know in what ways, these emissions from vehicles can be reduced? Transport Sector emissions can be reduced through infrastructure investments or land use policy. Traffic system management is not only intended to smooth the flow of traffic and enhance mobility but also have the benefits of reducing emissions through efficient fuel consumption. In recent history policymakers in metropolitan centers all over the developing world have been working to monitor and mitigate worsening levels of air pollution. The investment in road infrastructure development significantly lowers fuel consumption and emissions per kilometer. It is important to conduct air quality audits of all new major transport infrastructure projects as mandatory part of the environmental impact assessment reports. when we simply design a fast track to improve the traffic flow on the road, one weakness very often comes to fore that is addition of more traffic. Therefore, it is important to control traffic in parallel because congestion may be relieved a little but total emission may even increase (Gwilliam et al., 2004). Once road development project is completed, monitoring of air pollution becomes even more important for the management of air quality and implementation of anti-pollution laws. The process of monitoring helps identify pollution patterns, nature and concentration of pollutants and their harmful effects on the people living in that area, city and region (Arslan, 2003).

CHAPTER 3

RESEARCH METHODOLOGY

3.1. INTRODUCTION

The research is conducted with focus at urban air pollution generated by road traffic. Urban environment is a universal concern shared equally by the whole comity of nations around the globe these days. It is more severely felt in the developing countries because these countries are rapidly urbanizing, catching fast with the developed world. Urban air pollution related to traffic is a great concern due to its economic and health implications. The large cities in the developing world are attracting more people and consequently more vehicles are added to already huge number pool of vehicles. Large population increases the travel demand and travel demand, hence overburdening the existing road infrastructure. This addition in vehicles generates more air pollution. Local authorities redesign the road for the purpose of removing congestion and improve the air quality. The current research is designed to monitor the air pollution on a road which was previously a signaled road and now converted into a signal free corridor .The research measures the difference in air pollution parameters by comparing with pre and post project completion air quality parameters recorded at selected sites of the said signal free corridor. The difference between air quality of signaled road and signal free road is found out by monitoring the air quality at selected sites to further quantify the sustainability of a signal free corridor in an urban center.

Measurement of air pollution has been done by calculating emission factor of five different categories of vehicles on the basis of type fuel used in the vehicles and speed of the vehicles. Emission factor is defined by calculating average emission rate of a specific pollutant for a specific category of a vehicle. It may be called as an emission amount generated by a kilometer travelled of an hour travelled by that specific category of a vehicle. Vehicle emissions are calculated by multiplying an estimate of a distance travelled or time taken while running by a vehicle of that specific category with an emission factor (Frank et al., 2000). To calculate the emission factors for different categories of vehicles, operational street pollution model (OSPM) software has been used, which is operational and applicable dispersion model for assessment of air quality of streets. There is only single model of OSPM is available. OSPM has inbuilt data of emission factors for different fuel qualities and for different speed of vehicles. The calculations have been made on the basis of 1990 level fuel quality and model 2000 vehicles as of Europe because quality of fuel being used in Pakistan is equal to fuel standard used in Europe in 1990 and vehicle model engine quality equal to 2000 models.

The amount of fuel used is directly proportional to the air pollutants emitted. Pakistan adopted Euro 11 vehicle standard in 2009. The fuel used in Pakistan has high content of benzene (3.7-5%) (Yasin et al., 2008) and sulfur content is also high is diesel (0.5-1%) and in furnace oil (1-3.5%) when compared with international standards (Martin et al., 2006).

3.2. THE STUDY AREA

The geography of Lahore is a combination of various features of the land and climate of Lahore, Pakistan. Lying between 31°15′—31°45′ N and 74°01′—74°39′ E, Lahore is situated on the north and west by the Sheikhupura District, on the east by Wagah, and on the south by Kasur District. The Ravi River flows on the northern side of Lahore. Total land area of Lahore city is 1014 km^2 and is still growing. Jail road is a busy road in Lahore. Recently Gulberg and Jail road has been made signal free. To check the contribution of signal free corridor Four points have been chosen on the signal free corridor to compare their pollution level with the EIA study conducted before the start of the project. Another four points have been selected (two on the Jail Road and tow on the Mall Road) to compare the emission levels of signaled and signal free road. The eight selected points in the study area have been shown in Fig. 3.1. The pictorial view of the selected eight points have been shown in Fig. 3.2.

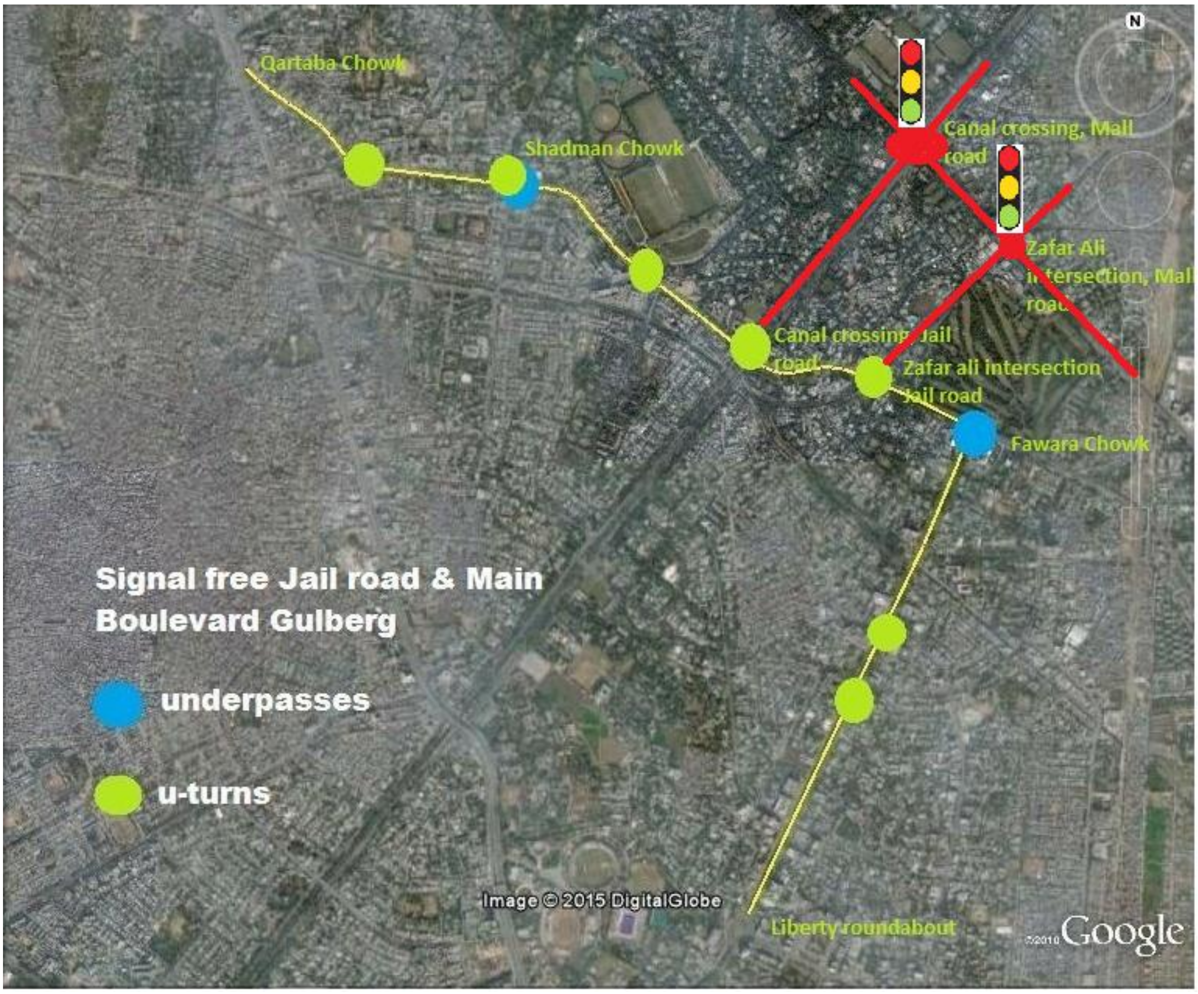

Fig. 3.1: Study Area (Signal Free Corridor)

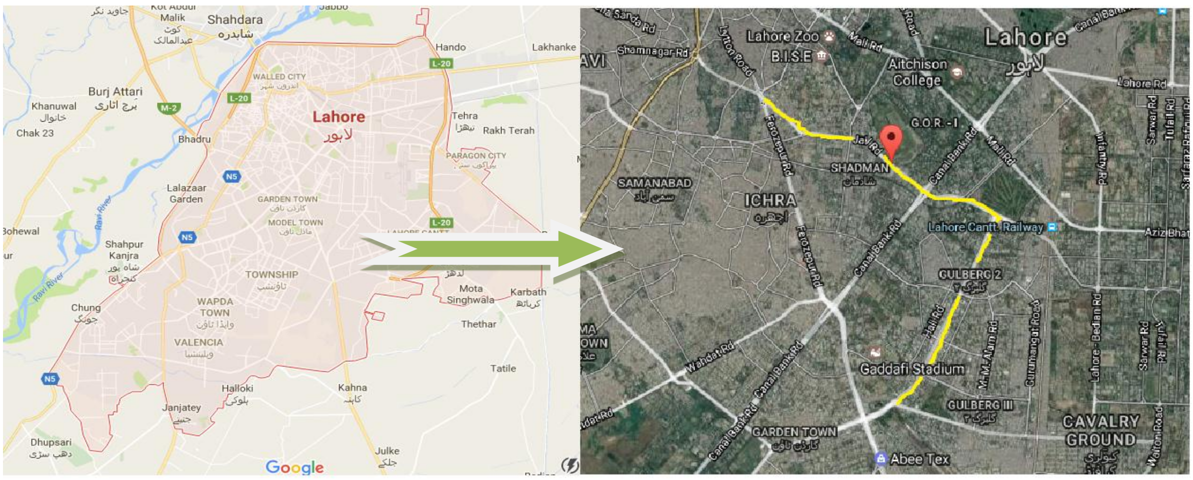

Fig. 3.2: Location of Signal Free Corridor Lahore Pakistan

3.3. AIR QUALITY ANALYSIS

Air quality data collected on hourly basis from selected locations at the signal free corridor for different days of the month of February has been recorded and tabulated along with data of selected locations as recorded in the EIA report. Air quality data on hourly basis was monitored at two signaled intersections at the Mall Road and two opposite locations at signal free corridor for comparison of air pollution parameters. Monitoring of four air pollutants of carbon monoxide (CO), Sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter (PM_{10}) was conducted through analyzers mentioned below in Table 3.1. The quantity of PM_{10} was monitored by gravimetric process and it was carried out at the time of monitoring of air pollution parameters at the selected sites. As the power to the analyzers was provided through generator, a special care was taken to avoid the generator emissions exposure to the air quality monitoring analyzers by placing generator at a suitable distance. A comprehensive calibration was done before running the air quality analyzers. Detail of air quality monitoring instruments has been given in Table 3.1.

Table 3.1
Detail of Air Quality Monitoring Instruments

Pollutant	*Analyzer*	*Range*	*Method*	*Detection Limit*
Carbon Monoxide	Horiba Ltd; Model APMA-370	0~50 ppm	non-dispersive infrared ray method (ISO4224)	0.1ppm
NO/NO_2 /NOx	Horiba Ltd; Model APNA-370	0~1 ppm	Chemiluminescence (ISO7996) method	1 ppb
Sulfur dioxide	Horiba Ltd; Model APSA-370	0~0.5 ppm	U.V. fluorescence method (ISO10498)	1ppb
PM_{10}	Fine Dust Sampler Model IPM-FDS 2.5/10	0~5 mg m-3	Gravimetric Method	-----

Note: No detection limit has been provided for PM_{10} by Horiba Company
Source: http://www.horiba.com/process-environmental/products/process/air-quality-monitoring/

3.4. ESTIMATION OF AIR QUALITY INDEX

The categorization of AQI can be described as clean, moderate, unhealthy and very unhealthy. The Pak-NEQS for $PM_{2.5}$ (for 24 hours) do stand revised downward from 40 µg/m^3 to 35 µg/m^3 and are notified with effect from January, 2013 (Auditor General of Pakistan, 2010). Punjab Environmental Protection Agency adopted the Pak-NEQS in respect of Air Quality Standards in August, 2016. The method of calculation of projected Air Quality Standard is described in the Table 3.2 (Abrar et al., 2014).

Calculation of the Air Quality Index was made according to the equation 3.1.

$$AQI = \left[\left\{ \left(CO/5 \right) + \left(NO_2/80 \right) + \left(PM_{10}/150 \right) + \left(SO_2/120 \right) \right\} / 4 \right] * 100 \quad (3.1)$$

Table 3.2
Criteria of Air Quality based on Air Quality Index

AQI	0-50	50-100	101-150	151-200	201-300	>300
	(orange)	(yellow)	(amber)	(purple)	(red)	(dark red)
Air Quality	Clean	Moderate	*Unhealthy for Sensitive	Unhealthy	Very Unhealthy	Hazardous

* Sensitive people means, people with low immunity like children and old people

CHAPTER 4

RESULT AND DISCUSSION

This chapter covers various aspects of traffic at a signal free corridor starting from main boulevard, Gulberg to Qartaba Chowk, Jail Road, Mozang. Diurnal traffic was counted at four selected sites at the signal free corridor as mentioned in EIA report prepared for the project of conversion to the Road into a signal free corridor. Air pollution monitoring was performed for 24 hours at six different selected sites of the signal free corridor and two parallel selected signaled intersections at the Mall Road. A comparison has been performed between the levels of air pollution parameters of four selected locations at the signal free corridor recorded before and after its conversion into a signal free corridor. Similarly air pollution levels of two locations at signal free corridor have been compared with the levels of air pollution of two signaled intersections at parallel signaled Mall Road. An assessment of variations in emissions from different types of vehicles was made with the help of Operational Street Pollution Model (OSPM) software with increase and decrease of speed of vehicles of different categories and with type of fuel standard.

4.1. VARIABILITY IN DAILY TRAFFIC ON SIGNAL FREE CORRIDOR

Signal free corridor was designed with a purpose to improve traffic on the road starting from Liberty Chowk, Gulberg to Qartaba Chowk, Jail Road. The signal free corridor has turned out to be a blessing for car users but has created problems for pedestrians, cyclists and rickshaw drivers. Vehicle speed has improved on the signal free corridor and it saw reduction in congestion at different locations previously under immense traffic load. This expansion of the road and its conversion into signal free corridor has invited increased number of road users who are using it to save their travel time and cost. Many a commercial, health and educational institutes like Liberty market, Hafeez Center, Siddique Trade Centre, Gadafi Stadium Sports Complex, Services Hospital, Punjab Institute of Cardiology, Kinnaird College, APWA College, Racecourse Park, Lahore College for Women are located on this signal free corridor which is pulling a huge number of vehicles to the road.

The traffic count for 24 hours at four different locations at signal free corridor is shown in the Fig. 4.1. Highest number of vehicles has been observed at Liberty roundabout, Gulberg especially in the morning from 8-10 am, at noon from 1-3 pm and 6-11 pm in the evening. A large number of people visit Liberty Market, surrounding commercial markets and restaurants in the area from 6 to 11 pm causing peak in traffic volume during that duration of day. The second highest number in vehicles may be seen at Shadman Chowk, especially in the morning from 7-10 am and at noon from 1-4 pm. Most of the people travel through Shadman to reach their offices, Kinnaird College, Lahore College, Punjab Cardiology Hospital, Services Hospital and Shadman Market.

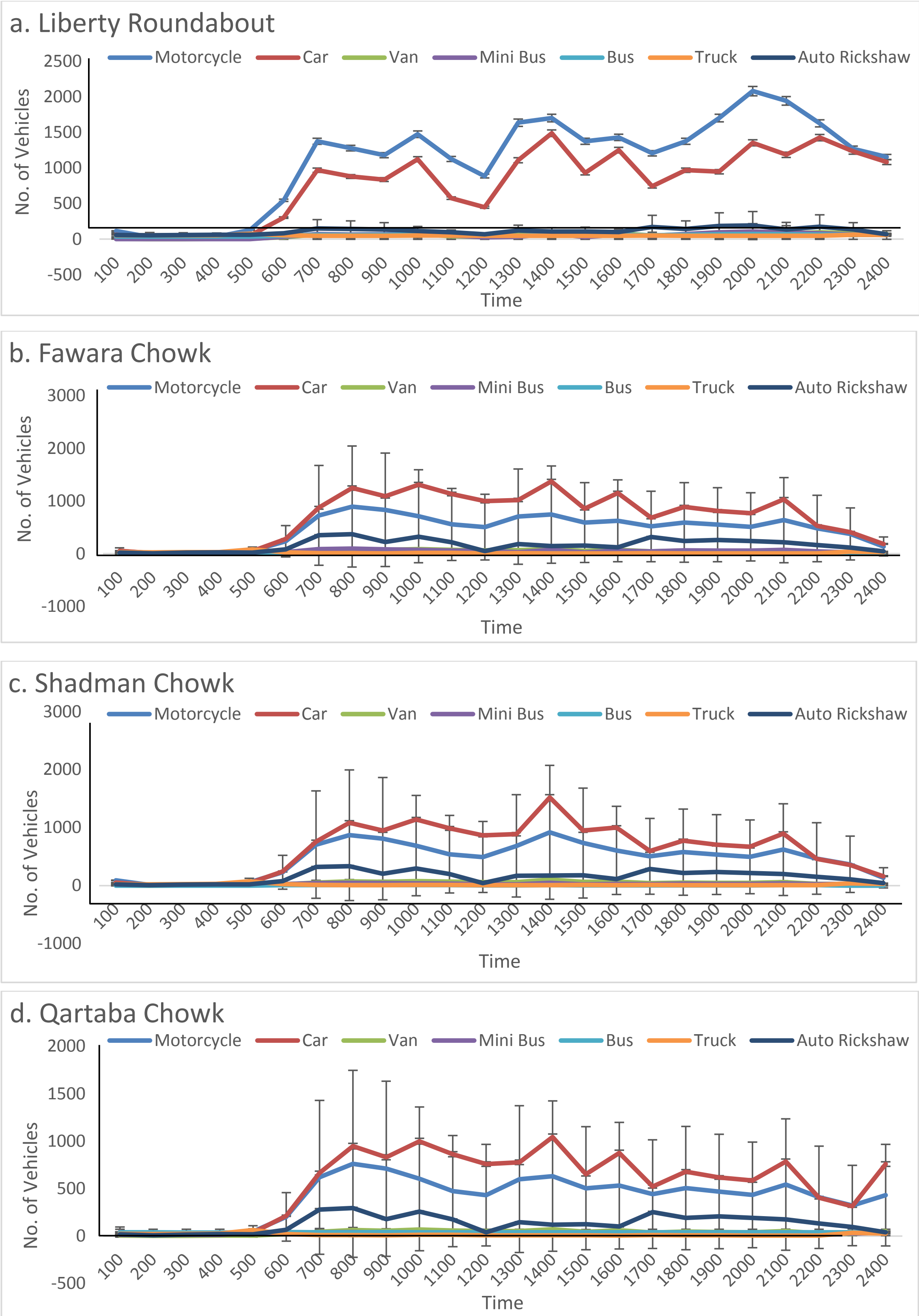

Fig. 4.1: Daily Traffic Trend on Different Spots on Jail Road (a) Liberty Rounabout, (b) Fawara Chowk, (c) Shadman Chowk and (d) Qartaba Chowk

4.2. TREND/VARIATION IN AIR POLLUTION

Diurnal air pollution trend of four major pollutants of air quality (NO_2, SO_2, CO and PM_{10}) at four different sites of signal free corridor is shown in the Fig. 4.2. The pictorial view of four selected sites is shown in Fig. 4.3. Maximum pollution is observed during peak hours (6-8 am, 1-3 pm and 6-8 pm) at all the four locations. It has been observed that pollution level decreases at noon due to high solar radiations, dispersion effect and high wind speed (Haider et al., 2017). Sulfur content (0.5-1%) is very high in diesel available in Pakistan as compared to Euro II standards (0.05%) (Martin et al., 2006). SO_2 emissions depend upon diesel fuel, therefore at day time SO_2 emissions remain low and well within NEQS. From 11 pm to 6 am SO_2 levels remains high due to entrance of heavy diesel vehicles in the city. Similarly, PM_{10} level also remains high at night due to heavy diesel vehicles. PM_{10} level also remains high during peak hours. NO_2 levels remains very high at all the four locations as NO_2 emissions are produced by 4-stroke petrol engines as well as by diesel vehicles (Yasar et al., 2013).

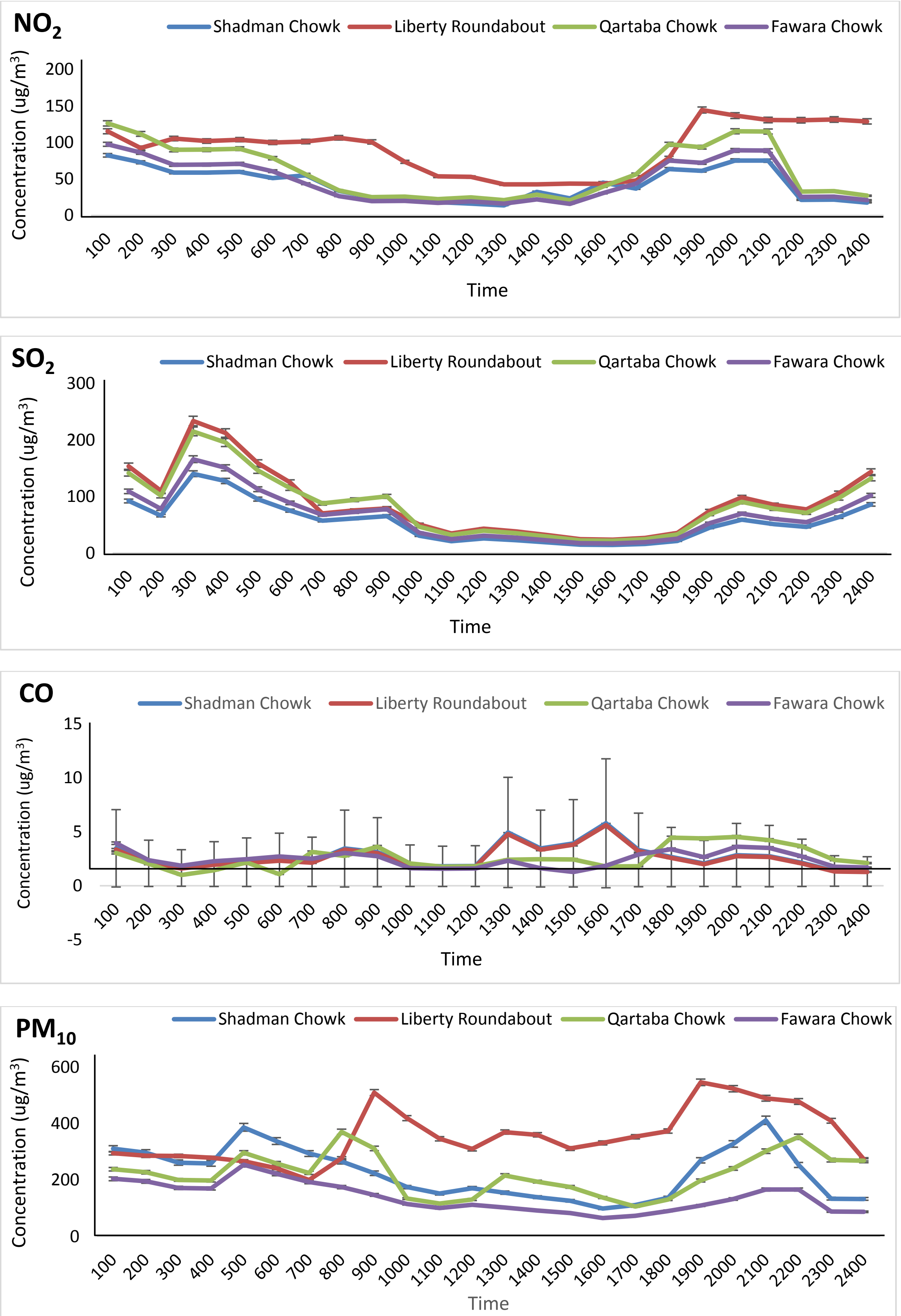

Fig. 4.2: Daily Air Pollution Trend at Different Spots of Jail Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}

4.3. COMPARISON OF AQI OF SIGNAL FREE ROAD WITH AQI OF A SIGNALED TRACK

It has been explained in the objectives of this research that pollution levels at two locations of signal free corridor shall be compared with pollution levels of two intersections of a parallel signaled road to ascertain the sustainability of a signal free road over a signaled road. Two locations at signal free corridor i.e. Zafar Ali Road - Jail Road intersection and Canal Road - Jail Road intersection were selected for monitoring the air pollution levels there. Further two signaled intersections opposite locations at a parallel signaled Mall Road i.e. Zafar Ali Road - Mall Road intersection and Canal Road - Mall Road intersection were selected for monitoring air pollution levels at a signaled track.

4.4. COMPARISON OF AIR QUALITY AT CANAL CROSSINGS

Very high traffic has been observed on canal crossing during peak hours. Although Jail Road crossing has been made signal free but still acute traffic congestion is observed there due to narrow underpasses at the both sides of Canal Road. Secondly two U-Turns have been provided at both sides of canal crossing at the Jail Road. The canal crossing at Mall Road is a very busy intersection. The signal at canal crossing at Mall Road usually observes very high traffic from all four sides. The pollution level is comparatively high at canal crossing at Mall Road but during some peak hours comparatively high pollution level has also been observed on canal crossing at Jail Road due to congestion and traffic blockage at Canal Road underpass and U-turns at Jail Road. Again high pollution level is observed during peak hours at these both locations. It can be concluded that benefits of a signal free track of Jail Road have been set aside by very narrow width of Canal Road underpasses and U-turns provided at Jail Road at canal crossing. Traffic congestion is witnessed at this point during peak hours. This congestion at canal crossing results into deterioration of air quality at Canal Road - Jail Road crossing. The comparative results of signal air quality at canal crossing at Mall Road and canal crossing at Jail Road has been shown in Fig. 4.4.

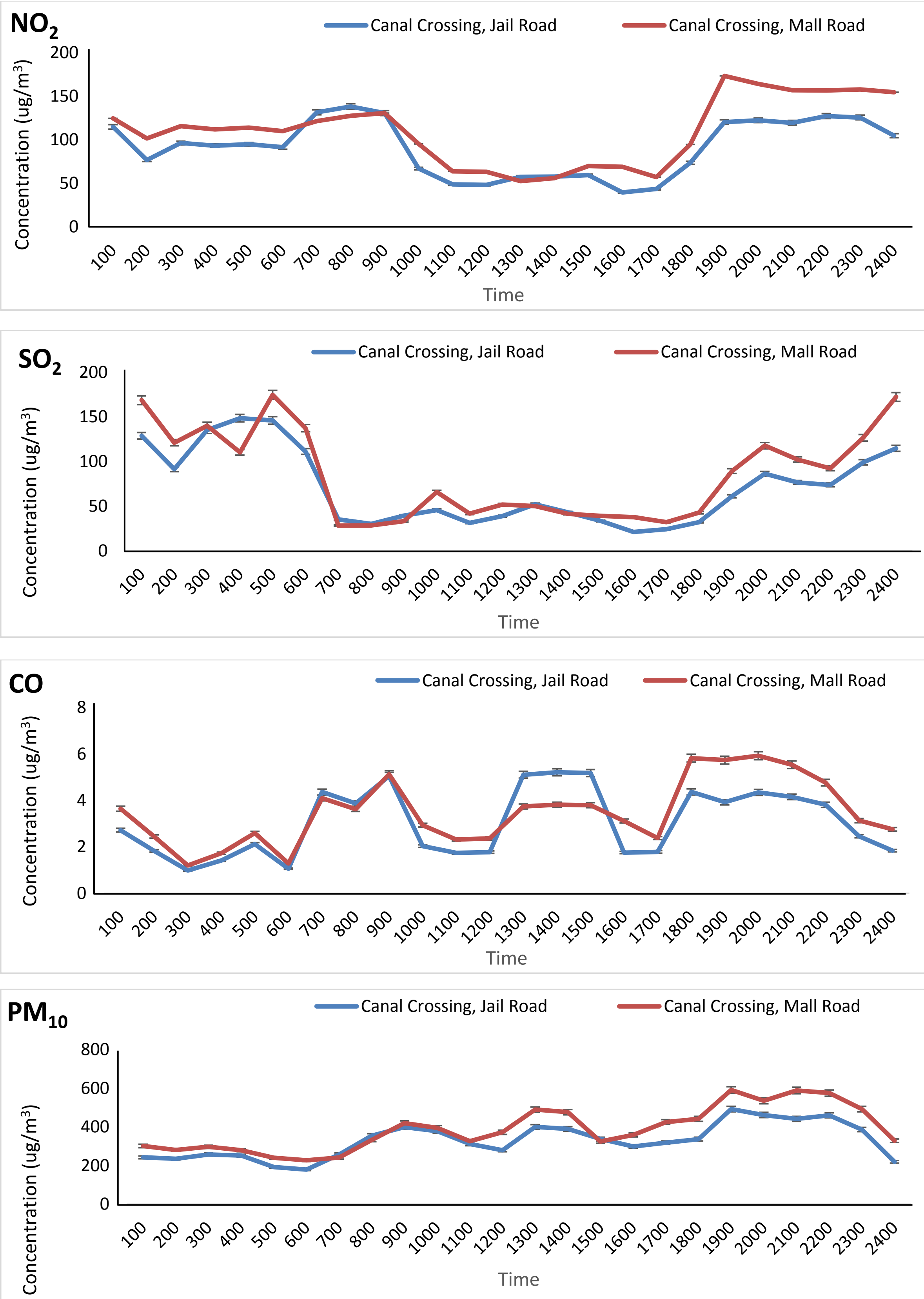

Fig. 4.3: Comparison of Pollution Level at Canal Crossing at Jail Road and Mall Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}

4.5. COMPARISON OF AIR QUALITY AT ZAFAR ALI ROAD INTERSECTIONS

There was a signaled intersection at Jail Road - Zafar Ali Road crossing before conversion of Jail Road into a signal free corridor. Now it has been made signal free by introducing two U-turns at both its sides at Jail Road for smooth flow of traffic towards canal and towards Sherpao flyover. The U-turn provided at Jail Road - Zafar Ali road for traffic moving towards Canal Road witnesses traffic congestion during peak hours. The traffic congestion at the U-turn results into lowering of vehicle speed and high pollution level at Zafar Ali intersection at Jail Road. The intersection at Mall Road - Zafar Ali crossing at Mall is a signaled intersection. Slightly high pollution level has been observed at this signaled intersection as compared with an opposite location at the signal free corridor. It can be concluded that benefits of signal free track at Zafar Ali Road - Jail Road intersection at Jail Road have been reduced by congestion of traffic at the U-turn provided at the Jail Road. The comparison between air quality of signal free location at Jail Road - Zafar Ali Road crossing and opposite signaled intersection of Mall Road - Zafar Ali intersections at Mall Road is given in Fig. 4.6.

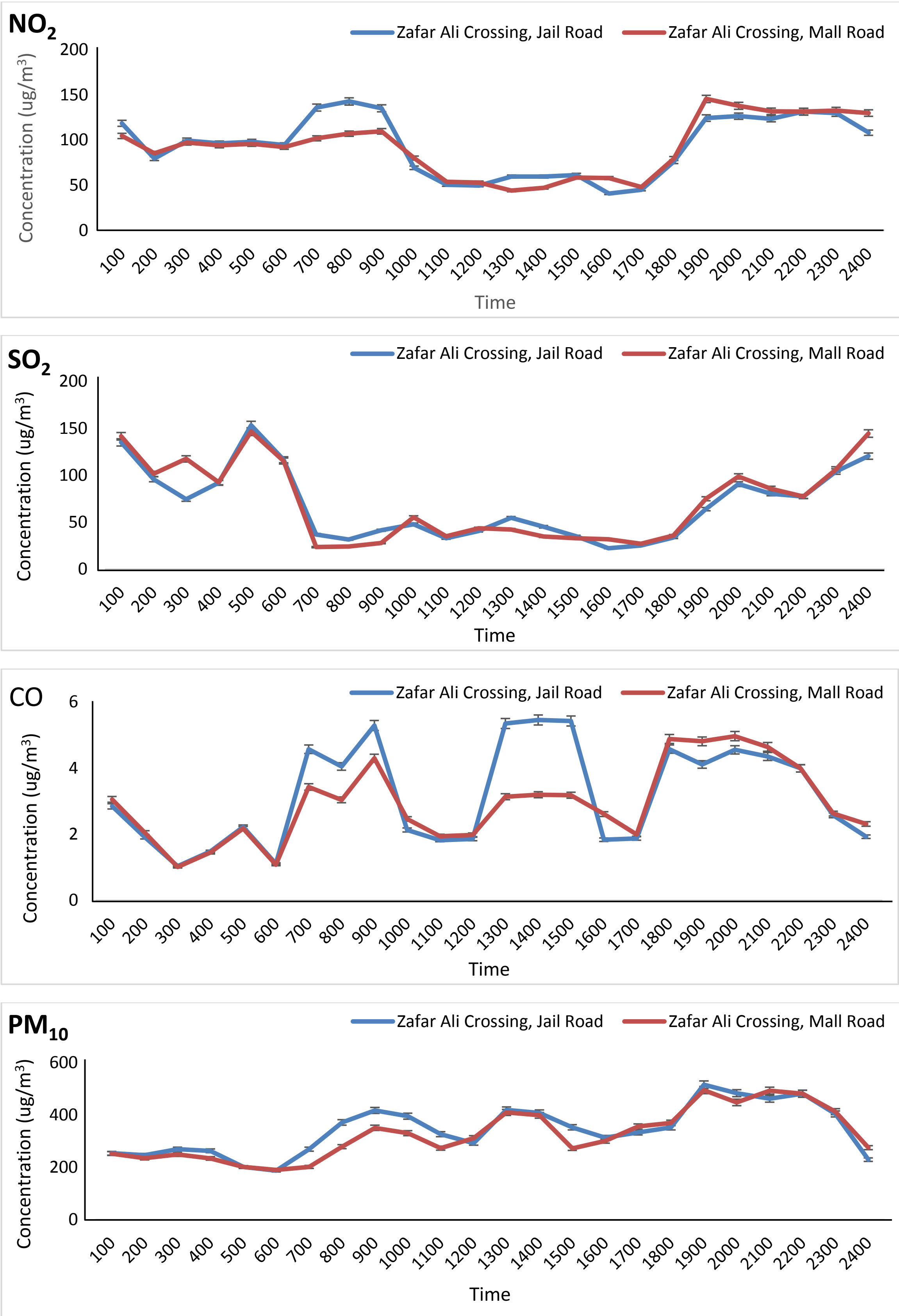

Fig. 4.4: Comparison of Pollution Level at Zafar Ali Crossing at Jail Road and Mall Road (a) NO_2, (b) SO_2, (c) CO and (d) PM_{10}

4.6. COMPARISON OF AIR QUALITY BEFORE AND AFTER THE PROJECT

The air quality of the Gulberg region was monitored through mobile air quality monitoring station, installed at Gadafi Stadium outside EPA Punjab office. The 24-hour data of 10th February, 2011 has been used for comparison with the current study. The second available study used as baseline data for comparison is a study conducted by the proponent agency for preparation of EIA report for the project. But there is an inherent shortcoming in study of EIA, air pollution monitoring was not performed for 24 hours. The current study has been conducted during February, 2017.

The comparison of air quality of 2015 and 2017 is shown in Fig. 4.8. The AQI of different locations is shown in Fig. 4.9. The Fig. 4.8 explains that NO_2, SO_2, CO and PM_{10} levels are high at Liberty roundabout in 2017 as compared to previous years (2011 & 2015). This increase in air pollution may be attributed to the traffic congestion at the U-Turns provided at both sides of the Liberty roundabout at main boulevard, Gulberg. These U-turns are the points where traffic moves very slowly and addition of more vehicles produces worst type of congestion during peak hours especially in the evening. The air quality has improved at Fawara Chowk as compared to the air quality recorded in EIA, 2015.

The AQI index at all four selected locations except Fawara Chowk is high in the February, 2017 as compared to the AQI of 2015. It is quite surprising that AQI recorded in EIA, 2015 is at very lower side even if it is compared with the AQI of year 2011 recorded by ambient air monitoring stations stationed at Gadafi Stadium. There it can be concluded that AQI (EIA, 2015) may not be representative a study. It might be possible that the decrease in AQI of 2015 than AQI in 2011 may be possible due to monitoring conducted for a short duration or monitoring performed after rain fall.

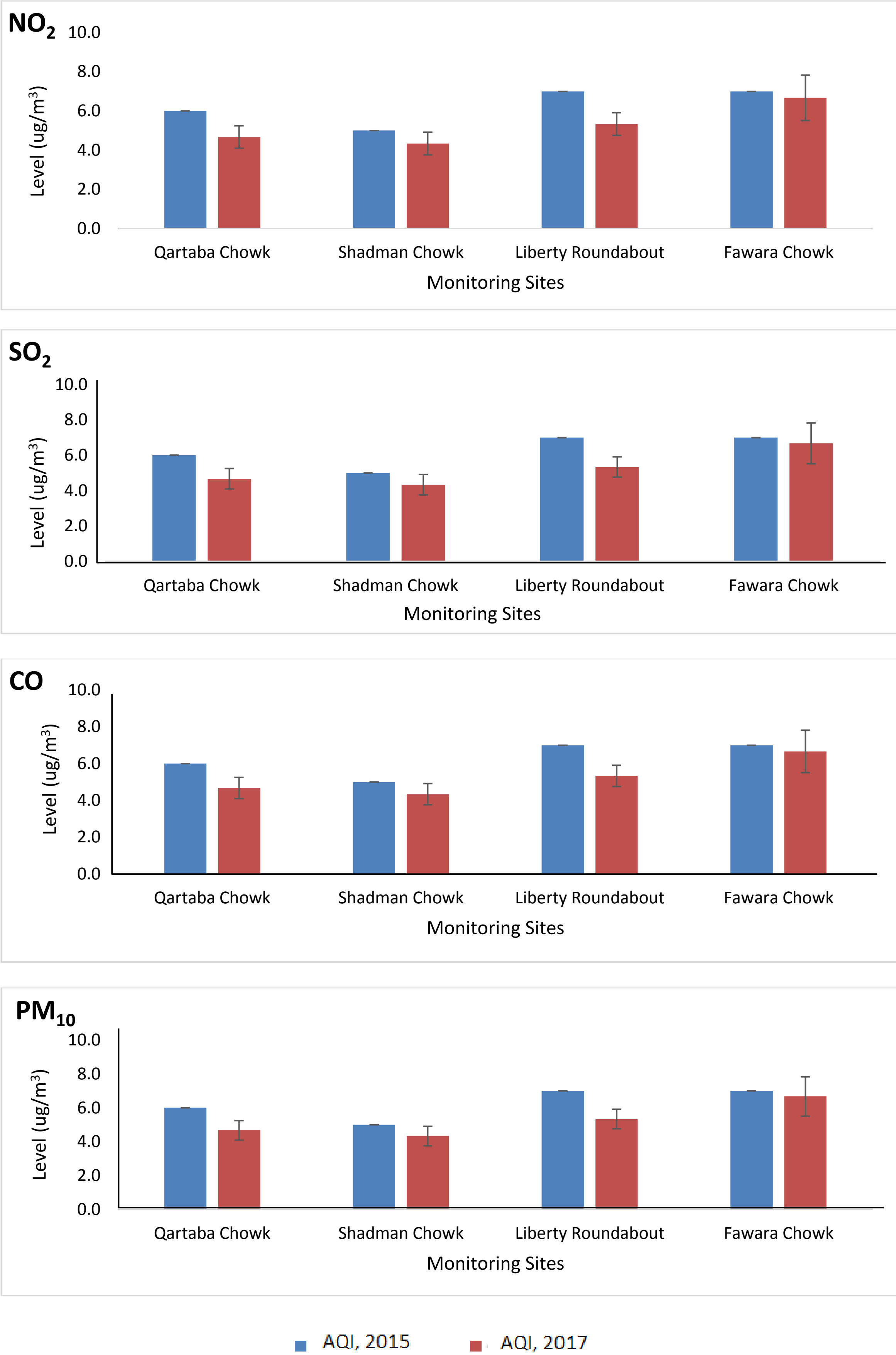

Fig. 4.5: Comparison of Previous and Current Studies

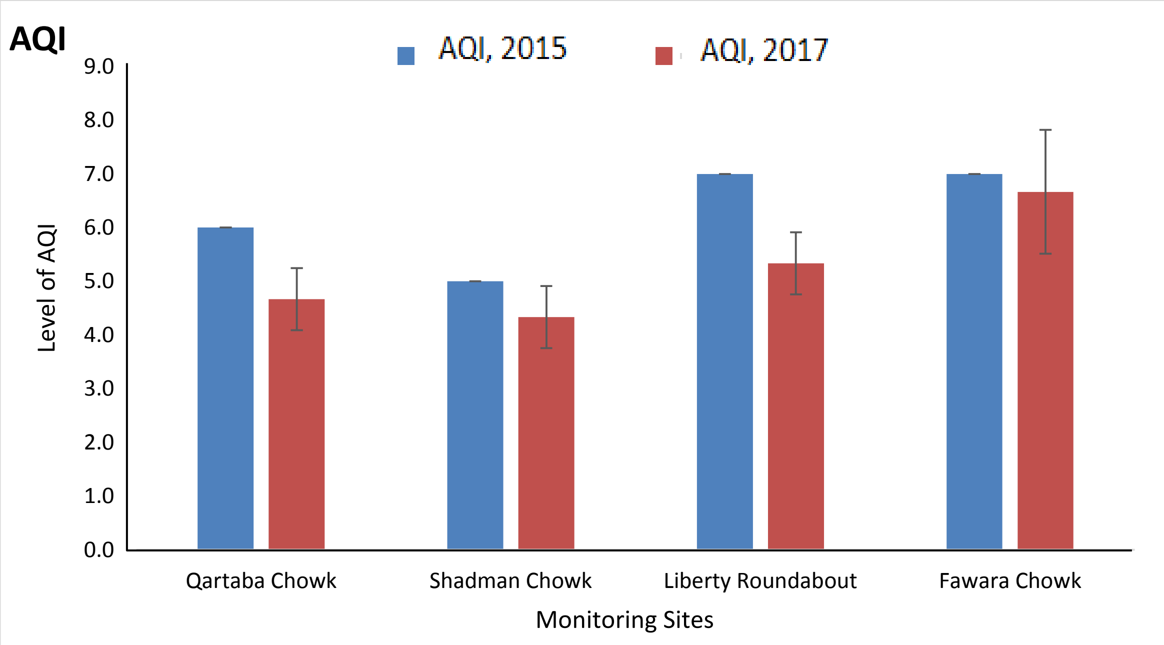

Fig. 4.6: AQI at Different Sites Before and After the Project

4.7. CALCULATION OF EMISSION FACTORS OF DIFFERENT VEHICLES

The emission factor of different vehicles has been estimated with OSPM software. The emission factor of vehicles depends upon fuel quality, engine type and speed of the vehicle. The fuel available in Pakistan is 1990s level as that of Europe and the engine quality of vehicles is around 2000 model of vehicles as that of Europe. The emission factors have been calculated by taking into account fuel quality, engine type and speed of vehicles. The emission factor of different vehicles at different speed is given in Fig. 4.7.

4.8. COMPARISON OF EMISSION FACTOR OF DIFFERENT VEHICLES

NOx emissions are produced due to reaction of nitrogen and oxygen at high temperature combustion in the engines. Relatively high temperature is observed in diesel engines which results in high NOx emissions. Fig. 4.7(a) shows high NOx emissions for heavy diesel vehicles like truck, bus and mini bus.

CO emissions are produced due to incomplete oxidation of hydrocarbons. Incomplete combustion of fuel mainly happens for diesel fuel but low emissions of CO are observed for diesel fuel due to presence of long chain hydrocarbons in diesel fuel. CO emissions are mainly produced by petrol vehicles (Yasar et al., 2013). Fig. 4.7(b) shows that maximum CO emissions are observed from cars as most of the cars use petrol as fuel.

Petrol used in Pakistan contains high content of benzene (3.7-5%) as compared to Euro II standards (1%) (Yasin et al., 2008). Fig. 4.7(c) shows high emission factors of benzene for petrol vehicles as compared to diesel vehicles.

PM_{10} and $PM_{2.5}$ are produced mainly due to un-burnt hydrocarbons by vehicles. Poor maintenance of diesel engines causes below the optimum level combustion of hydrocarbons resulting into higher emission of particulate matter. Fig. 4.7(d) and 4.7(e) shows high emission factors of PM_{10} and $PM_{2.5}$ for diesel vehicles as compared to petrol vehicles.

4.9. EFFECT OF SPEED ON EMISSION FACTORS

Speed has very significant effect on reduction of emission factor of vehicles. The emission factor of vehicles decreases up to the speed of 60 Km/h and starts rising for speed increasing above 60 Km/h. The emission factors are highest during cold starts (idle position) and also higher during congestions when vehicle speed is often at a speed less than 10 Km/hour. Similarly, very high emissions are observed on signals due to idle position of vehicles. Signal free corridors improve the vehicle mobility which results in reduction of emission factors for all vehicles. A trend of decrease of emission factor for vehicles in shown Fig. 4.7. A similar decrease for emission of motorcycles has been obtained with improvement in speed.

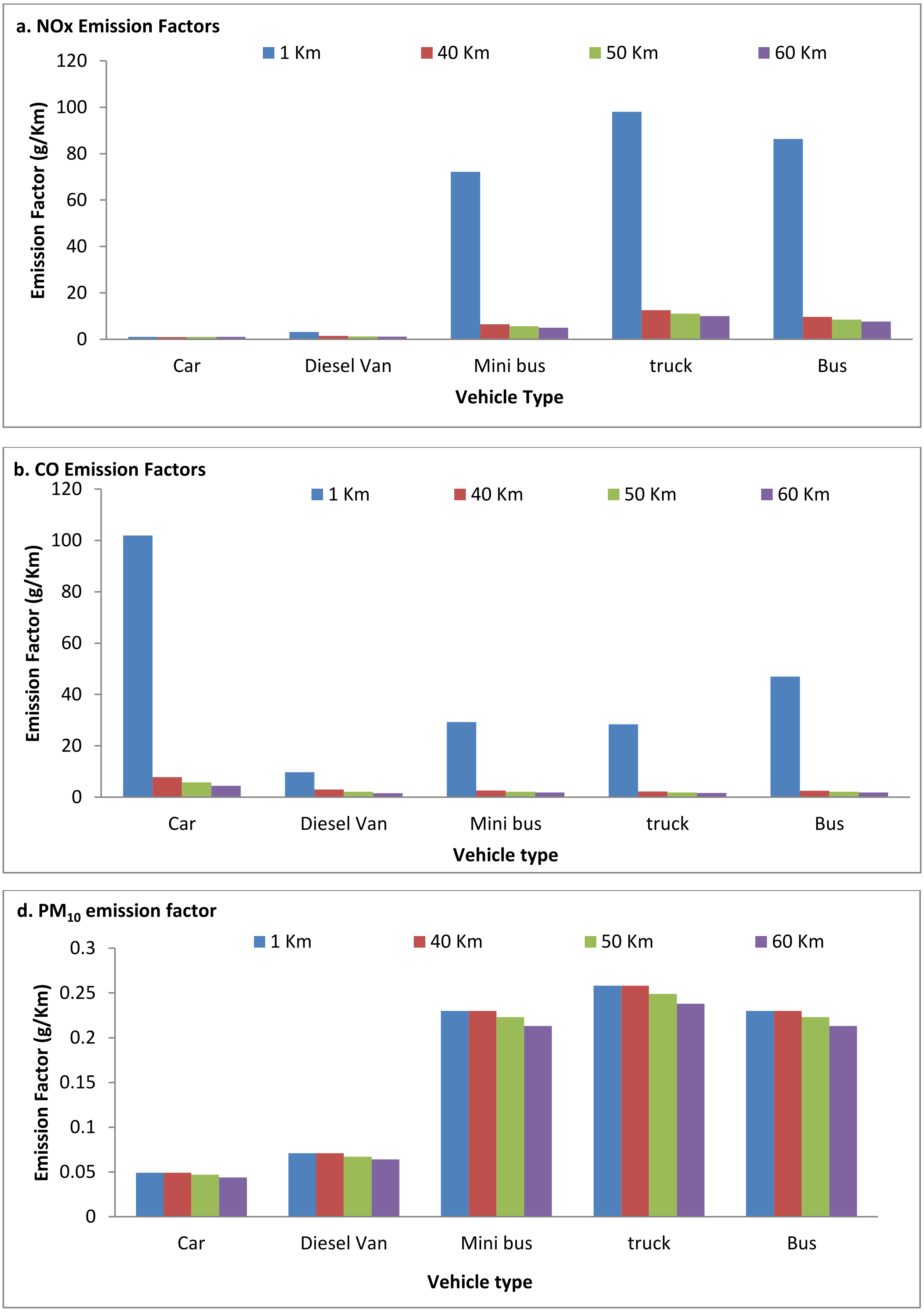

Fig. 4.7: Calculation of Emission Factor of Vehicles with OSPM at Different Speeds

4.10. CONCLUSIONS

- AQI has improved by 22.2%, 13.3%, 23.8% and 4.8% on four selected points of Qartaba Chowk, Shadman Chowk, Fawara Chowk and Liberty roundabout respectively as compared to pre-project conditions (2015).

- AQI of different locations at signal free corridor is now higher than AQI recorded in 2011 by ambient air monitoring station of EPA established at Gadafi stadium. But it is noted interestingly that AQI of Liberty roundabout calculated in 2015 (EIA) is lower even than AQI (2011) of Gadafi stadium and AQI (2017) of Liberty roundabout observed for current study. This area has seen a huge commercialization of previously residential spaces and increase in traffic over these years resulting into huge influx of people, generators and vehicles. Therefore, it does not appeal to common sense that AQI has lowered in 2015 and 2017 than 2011. It raises a question mark on the study conducted for the preparation of EIA (2015) for the project of converting the said road into a signal free corridor.

- Comparison of AQI of two signaled intersection on parallel Mall road with two non signaled intersections at the signal free corridor shows that AQI at signal free corridor has improved for good due less congestion and non-stoppage of vehicles resulting into less emissions.

4.11. FUTURE RECOMMENDATIONS

i) Many issues regarding the sustainability of a signal free corridor in an urban area have cropped up. Therefore, it is need of hour to conduct a comprehensive study to ascertain the significance of reservations being shown by general public, road users and urban road development experts over sustainability of the signal free corridor through a social survey.

ii) Transport sustainability is a new concept for developing world. There are number of transport sustainability indicators suggested by different local and regional studies. A comprehensive study can be launched to select transport sustainability indicators for different roads, cities or regions of Pakistan. Transport sustainability index of different roads, cities or regions can then be determined according to selected indicators.

iii) Another glaring fact is the unavailability of proper parking places to cater the ever-increasing parking demand. The area was originally a planned residential area and it has now been allowed to be used for commercial purposes. The space is being covered by numerous skyscrapers. These plazas are visited by huge number of persons daily bringing more vehicles to the area requiring more parking spaces.

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