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ASSESSMENT OF STREET AIR POLLUTION THROUGH OSPM MODEL IN LAHORE, PAKISTAN

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Abstract

Traffic emissions are one of the main contributors in worsening the air quality of developing countries like Pakistan. The current research work is an effort to find out emission factor of different classes of vehicles as well as to model the certain air pollutants level on five different main streets of Lahore, Pakistan. The Town Hall air quality monitoring station at Mall road is taken as background station. The data of street configuration, background urban air pollution, meteorological conditions, diurnal traffic count and emission factor of vehicles was calculated to model the street air pollution. Operational Street Pollution Model (OSPM) was used to model the street pollutants. $PM_{2.5}$ levels exceed National Environmental Quality Standards (NEQS) during all months of calendar year, while SO_2 and NO_2 exceed NEQS during entrance of heavy traffic at night in the city. Diesel vehicles have high SO_2, NOx, $PM_{2.5}$ and PM_{10} emission factors; while gasoline vehicles have high CO emission factors. Industrial region has relatively high level of SO_2 emissions; while roadside have relatively high level of CO emissions. A significant correlation (r-value > 0.5) was observed between modeled and observed results for all the streets for the NOx, SO_2 and CO levels, except for NOx level at Gulberg (r-value= 0.42). The better modeling results have been observed for those streets which are relatively polluted spots and are close to the background station.

Keywords: background, emission factor, modeling, Pakistan, street configuration, traffic

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1. Introduction

According to the data provided by monitoring stations in Lahore, Rawalpindi, Karachi and Peshawar, the $PM_{2.5}$ and PM_{10} concentration has been found almost six times higher than WHO guidelines (Kakareka et al., 2015). Many research results also pointed out that public health has been harmed to a considerable level by vehicular emissions especially by fine particulate matter like $PM_{2.5}$ and PM_{10} (Buchholz et al., 2013; Colvile et al., 2002; Holnicki et al., 2010; Mediavilla-Sahagún and ApSimon, 2006; Oxley et al., 2009; Park et al., 2006). Studies showed that highest air pollution has been observed in Pakistan, Iran and India during winter season leading to more respiratory patients during autumn and winter (Aneja et al., 2001; Gholampour et al., 2014; Haider et al., 2017). The high levels of $PM_{2.5}$ are mostly due to exhaust emissions of automobiles, generators and industrial stacks. Khodeir has estimated that dominant source of $PM_{2.5}$ are vehicular and industrial exhaust emissions (Afzali et al., 2017).

Pakistan is going through a phase of industrialization and motorization, which has strong correlation with elevated urban air pollution. Intense traffic volume and rich population density could result in different forms of air pollution (Stankovic et al., 2015). The level of ambient air pollution remains very high on most of the roads of Lahore throughout the year due to vehicular traffic load. The urban population of Lahore has been increasing at very high rate of 3% per annum (JICA, 2012). One of the main reasons is migration of individuals from small cities to Lahore due to availability of educational,

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medical and employment facilities in Lahore. The private vehicle ownership in the Lahore has come up with 17% annual increase in the recent few years (JICA, 2012). Heavy traffic load has been observed on the key roads of Lahore. The amplified number of cars is one of the main causes of congestions and safety for motorized and non-motorized mode users (Esmael et al., 2013).

Many studies have observed long life of days and weeks for $PM_{2.5}$ and lower particles (Popescu et al., 2011; Stefan et al., 2013; Vincze-Csom et al., 2012). In a study in Indonesia, high content of Pb has been observed in fine and coarse particles as compared to nearby residential areas (Yazdi et al., 2016). It has been estimated that black carbon was 50% content of the fine particles in Dhaka, Bangladesh, before adoption of control policies (Zhai et al., 2016). Global warming due to vehicular emissions not only endanger public health but also jeopardizes national security. Himalayan glaciers has been considerably reduced due to high level of greenhouse gases (Kulkarni and Karyakarte, 2014). Whereas, Extreme rainfall events are being observed in the Indian region due to climatic changes (Srinivasan, 2013).

Air quality modeling soft-wares has an important role in management and prediction of those urban emissions, which are crucial for urban air emissions management (Gulia et al., 2015). There is always an uncertainty in modeling results especially in urban areas (Holnicki and Nahorski, 2015). But still modeling technique is quite useful to evaluate air pollution levels. Parameterized models include road air pollution model named "Operational Street Pollution Model (OSPM)". OSPM is a combination of plume and box model. Plume model is used to calculate concentrations of exhaust gases box model is used to calculate the recirculating parts (Berkowicz, 2000). Street turbulence calculation is the one of the significant feature of OSPM. The street turbulence is considered to consist of two portions: a wind speed reliant part and traffic induced turbulence part. The traffic induced turbulence part dominates in case of low wind speed. This is because highest concentrations usually occur in near calm wind situations, proper 326 modelling of these conditions is critical (Kastner-Klein et al., 2000; Ketzel et al., 2000).

The Danish Operational Street Pollution Model (OSPM) belongs to this category of parameterized models. In the OSPM concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street (Berkowicz, 2000). One of the main features of OSPM is the modelling of turbulence in the street. There are two parts of the turbulence in the street is assumed to be composed of two parts: first part depends on wind speed and second part depends on traffic induced turbulence. The second part due to traffic induced turbulence dominates during calm (low wind speed). Because the highest concentrations usually occur in near calm wind situations, appropriate 326 modelling of these conditions is crucial (Kastner-Klein et al., 2000; Ketzel et al., 2000). The Operational Street Pollution Model (OSPM) is used to model the air pollution at five busy roads of Lahore. The notable growth of population and its movement on the streets, have made the transport sector as a main sector responsible for air pollution (Mitran et al., 2012). The OSPM model is a street canyon pollution dispersion model, which has been widely used to model air pollution. The basic data required for OSPM comprises of flow conditions of different automobiles in streets, street configuration and metrological conditions (Berkowicz et al., 1997; Hertel and Berkowicz, 1989). A combination of plume and box model is used to model the dispersion and transport of pollutants. Currently, OSPM has been widely used to calculate traffic pollution and pollution trends in European streets (Berkowicz et al., 1997). The Gaussian plume model measures the direct contribution from the automobiles and the box model is used for the mixed ambient air pollution circulating on the road due to existence of hurdles around the road (Berkowicz et al., 1997). The OSPM has also been successfully used to model NOx emissions in Chembur (industrialized and congested area with automobiles, near Mumbai India) (Kumar et al., 2016). The PM_{10} emissions have been successfully modeled on five streets of Izmir, Turkey (Elbir et al., 2011). The OSPM model has also been successfully used in Stockholm, Helsinky, Copenhagon, China, USA, Vietnam and India (Aquilina and Micallef, 2004; Berkowicz et al., 2008; Fu et al., 2000; Jensen et al., 2009; Mensink et al., 2006; Vardoulakis et al., 2007; Ziv et al., 2002). The term street canyons have been used for those roads or streets which are not necessarily covered by continuous walls or buildings on both sides (Vardoulakis et al., 2007). The OSPM can calculate pollutants level of roads with different height adjacent buildings, with wide range of height/ width ratios, buildings with openings and even open streets (Berkowicz et al., 1997). Wide range of models have been developed after considering number of related parameters. Currently Geospatial Monitoring of Air Pollution (GMAP) model of USEPA is a good example of high resolution mobile mapping of air pollutants from vehicles (Deshmukh et al., 2016).

Since the air quality monitoring involves too much financial as well as human effort. In many countries air quality has been monitored through different well-known models. The purpose of this research is to model the air quality on different selected roads through a well-known street air quality model (OSPM), by incorporating background air quality monitoring station data. The similarities between actual and modeled results will define the applicability of the model for its long run use in other cities and other roads as well. This study has defined the emission factor of different vehicles depending on the fuel and vehicles standard being used. Modeling of air pollution can save lot of money and effort especially for the developing countries. It is easy to monitor the air pollution in different cities of a province through reliable air pollution models. Currently only limited air quality monitoring stations are available throughout the country. No or very little air pollution monitoring data is available for most of the cities. With defined emission standards different other models can also be designed to model the air pollution of the cities. There are several common air pollution exposure modeling approaches widely used in the field, including CMAQ, RLINE etc., but OSPM is selected because of its special scope for road side air quality modeling.

2. Material and methods

Urban air quality is being monitored in the Lahore city with one mobile and two fixed air quality monitoring stations. The fixed air quality monitoring station installed at the Town Hall building at Mall road has been chosen as urban background ambient air emissions monitor in the current study. The Fig. 1 Shows the whereabouts of five selected streets and air quality monitoring stations. Population density of Lahore varies from 100 persons per hectare to 450 persons per hectare from outer to inner zone of Lahore respectively. It has been estimated that around 80 % of the population has been living in a radius of 7-8 km in the center of the city (JICA, 2012). Operational Street Pollution Model (WinOSPM version 5.0) has been selected for the modeling of air pollutants. Plume (Gaussian) and box model are combined in the OSPM Model. The Gaussian part calculates the concentration of emitted pollutants, box model deals with the recirculation part of the pollutants in the street and a simple chemical model for interdependent pollutants: NO, NO_2 and O_3 (Berkowicz, 2000). The OSPM software requires data like street configuration, background emissions and meteorological data (wind Speed, wind direction, solar radiations, temperature and relative humidity), diurnal vehicle data, average speed of vehicles and emission factor of vehicles. Solar radiation data is required to calculate NO_2 level. In the first step the configuration of streets is calculated. The street configuration includes road width, building height and street axis orientation from north side. More over the 24-hr data of different vehicle classes and average speed of vehicles has been calculated. The street configuration of five different streets and measurement period is given in Table 1.

Six air pollutants i.e. CO, SO_2, O_3, $PM_{2.5}$, NO, NO_2, NOx, HCs and meteorological factors have been monitored through Town Hall background air quality monitoring station. During May, 2016, 24-hr air quality of five selected roads was monitored through mobile air quality monitoring station. The air quality at different other spots like hotspots, industrial area and rural site has also been monitored. The specifications of analyzers are given in Table 2.

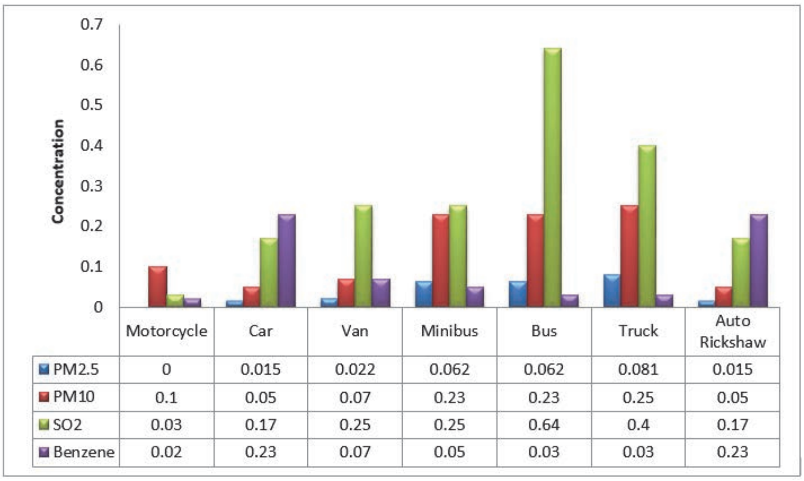
Fig. 1. Study Area (Location of streets and air quality monitoring station)

Table 1. Street configuration and measurement period

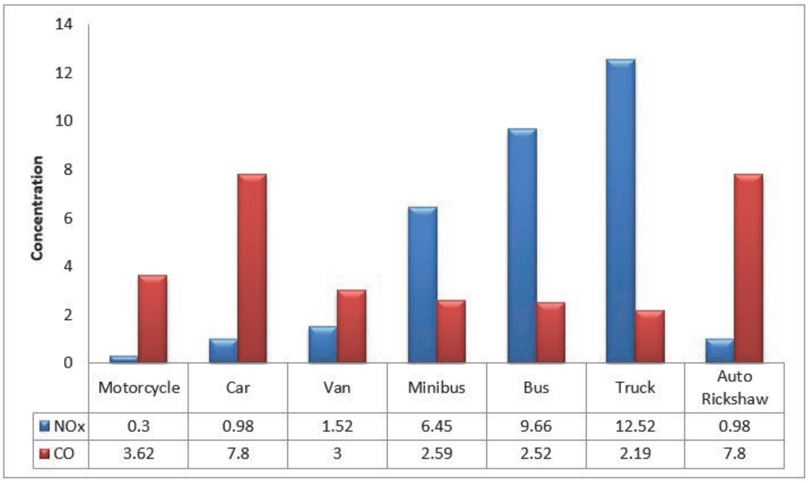
No.	Street Name	Building Height (m)		Average Street Width (m)	Orientation	Average Speed of vehicles (Km)	Measurement Date
		Side 1	Side 2				
1.	Ferozepur Road	10	08	40	108°	35-40	9 May, 2016
2.	Gulberg Road	15	12	60	63°	50	10 May, 2016
3.	Jail Road	10	8	45	143°	50	11 May, 2016
4.	Mall Road	8	7	35	148°	35-40	12 May, 2016
5.	Multan Road	8	4	35	100°	40	17 May, 2016

Table 2. Specification of analyzers of air quality monitoring station

Parameter	***Instrument Model***	***Min. Detection Limit***	***Method***	***Detection Range***
Ozone	APOA-370	0.5 ppb	UV photometry method	0~1ppm
Hydrocarbon	APHA-370	0.1 ppm	Converter oven method	0~50 ppm
CO	APMA-370	0.1 ppm	ISO-4224 (NDIR method)	0~50 ppm
$PM_{2.5}$	APDA-370	5 μg/m^3	ISO-6349 (β-ray absorption method)	0~5 mg m^{-3}
Sulfur dioxide	APSA-370	1 ppb	ISO-10498 (U.V. fluorescence method)	0~0.5 ppm
NO/NO_2/NOx	APNA-370	0.5 ppb	ISO-7996 (Chemiluminescence method)	0~1 ppm



(a)



(b)

Fig. 2. Emission factors of different vehicle: (a) $PM_{2.5}$, PM_{10}, SO_2 and Benzene; (b) NOx and CO

The emission factor of seven different vehicles has been calculated through OSPM software. The emission factor for $PM_{2.5}$, PM_{10}, NOx, Benzene and CO have been calculated through OSPM by taking into account the fuel characteristics of 1990 levels 2000 model Euro II vehicles as of Europe, for an average speed of 40 Km. Emission factorof SO_2 is adopted from a study in Vietnam, due to comparable conditions (Hung, 2010). Emission factor of gasoline auto rickshaw are considered equivalent to car due to similarity of emissions level as prescribed by Yasar et al. (Yasar et al., 2013). Fig. 2 shows emission factor of 7 different kind of vehicles.

$PM_{2.5}$ and PM_{10} levels have not been modeled, due to their valuable interference from sources other than automobiles in Lahore. High dust (PM_{10} and $PM_{2.5}$) has been observed in Lahore, from road dust and many other construction activities like Orange Line Metro Train project. CO, SO_2 and NOx have been modeled to check the performance of OSPM.

3. Results and discussion

It has been studied that motorcycles are the dominant vehicle class in the streets of Lahore. Cars (cars, jeeps and pickups) comprise second big category. As average of five streets motorcycles, cars, auto-rickshaws, vans, minibuses, trucks and buses population are 53%, 31%, 10%, 3%, 2%, 0.63% and 0.31% respectively. The diurnal pattern of traffic is almost same at all the selected roads of Lahore. Schools, colleges and Government offices usually observe starting time between 7-8 am. Banks and private offices usually observe 9 am as starting time. The business hubs and shopkeepers usually see their offices at 10-11 am. So, 8-10 am are usually peak hours in the morning and 1 pm to 2 pm are usually school off time, which usually lead to congestion on roads, around 1-2 pm.

The off time from Government offices is around 3-4 pm, while 5 pm is off time from banks and private offices. The second highest peak has been observed from 1-4 pm. The business hubs and shopkeepers usually wind-up their tasks from 7-10 pm, which lead to traffic load at 7-9 pm on roads. The heavy traffic is allowed from 11 pm to 6 am in the main city, which results in enhanced diesel fuel related pollutants (SO_2 and NOx) at 11 pm to 1 am. The bus traffic remains almost nil from 11 pm to 6 am.

$PM_{2.5}$ levels exceed NEQS throughout the calendar year. SO_2 and NO_2 emissions exceed NEQS during peak hours in the morning and at night, especially during introduction of heavy vehicles at 11 pm. Pollutants level remain low during day time due to high solar radiation and dispersion effect. Air quality has been monitored at different spots like traffic hotspots, road side, industrial area, urban background (background urban air quality monitoring station) and rural site. The results depict that CO remains in compliance at all spots, while $PM_{2.5}$ exceed NEQS at all spots. SO_2 level remains relatively high in industrial area; while CO level remains relatively high at roadside. A comparison of pollution level at different spots has been given in Fig. 3. The pollutants level at different roads depends upon number of vehicles, average speed, wind speed wind direction, solar radiations, temperature, dispersion level and many other conditions. The pollutants level was monitored through ambient air quality monitoring station on five different roads during May, 2016. Air quality was monitored for 24 hours on each road. The comparison of observed, modeled and background results is shown in Fig. 4. Table 3 presents correlation between modeled and actually monitored data. The correlation results depict the resemblance between trends of the modeled and actual results.

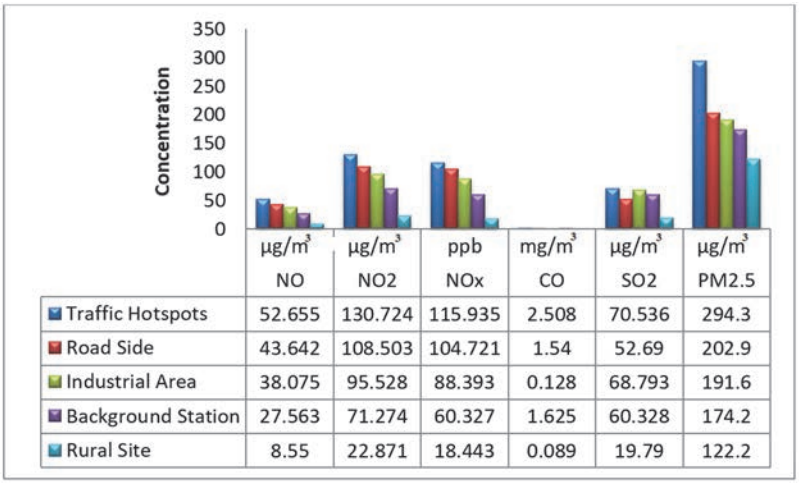


Fig. 3. Comparison of air quality at different locations in Lahore

Table 3. Correlation between modeled and observed results for different streets of Lahore

No.	*Street Name*	*Pollutant Name*	*Pearson Correlation (r-value)*
1.	Ferozepur Road	SO_2	0.63
		NOx	0.68
		CO	0.53
2.	Gulberg Road	SO_2	0.66
		NOx	0.42
		CO	0.72
3.	Jail Road	SO_2	0.80
		NOx	0.66
		CO	0.66
4.	Mall Road	SO_2	0.92
		NOx	0.92
		CO	0.88
5.	Multan Road	SO_2	0.57
		NOx	0.73
		CO	0.67

The observed results on different streets are higher than background results except for some duration at Jail road and Gulberg road. This might be due to high width and fluctuating building heights of Jail and Gulberg roads. The modeled data of NOx is slightly higher at day times but quite consistent at night-time for all the monitoring points. The modeled CO shows significant correlation with the observed results of CO for Gulberg (r-value = 0.72) and Jail road (r-value = 0.66). For Mall and Multan road, concentration of modeled CO is slightly higher at day time. The observed concentration of CO at Ferozepur road (r-value = 0.53) is much fluctuating, may be due congestion, high building height and enhanced inversion due to metro-bus bridge in between the road. The modeled concentration of SO_2 has much correlation with the observed results as shown in Fig. 4; but the results are different for different streets. The modeled concentration of SO_2 at Ferozepur road and Multan road is slightly low from 10-12 pm and slightly high at night. At Gulberg road, modeled concentration is much higher than observed from 1 am to 10 am. Overall modeled SO_2 data shows significant correlation with the observed data. Modeled SO_2 has significant correlation with minimum r-value = 0.57 for Multan road and maximum r-value = 0.92 for Mall road.

Modeled NOx has minimum correlation (r-value = 0.42) at Gulberg road and maximum correlation at Mall road (r-value = 0.92). Modeled CO has minimum correlation at Ferozepur road (r-value = 0.53) and maximum correlation at Mall road (r-value = 0.88). The modeling results have shown much correlation with observed results, as did by many previous studies. The background data of $PM_{2.5}$ is available, but not modeled due to much contribution of $PM_{2.5}$ and PM_{10} from sources other than vehicles in Lahore.

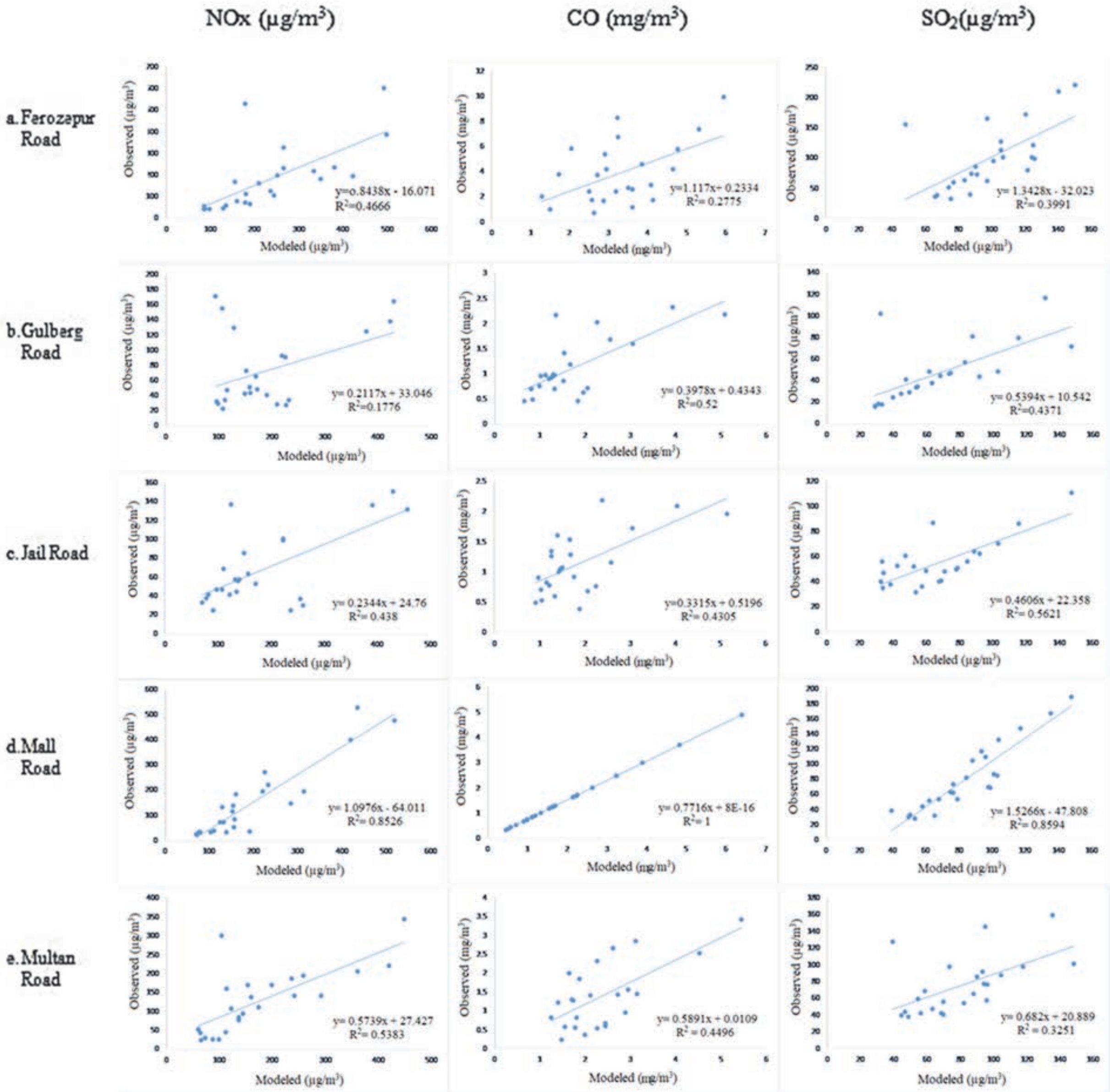


Fig. 4. Comparison of observed and modeled results:
a. Ferozepur road; b. Gulberg road; c. Jail road; d. Mall road; e. Multan road

4. Conclusions

Air pollution has turn out to be a hot issue for the Lahore city. High level of pollution has been observed during peak hours on most of the roads of Lahore. Peak hours have been observed from 8-10 am, 1-2 pm and 7-9 pm on all streets.

$PM_{2.5}$ exceeds NEQS throughout the calendar year (with minimum level of 42 μg/m^3 in August to maximum of 230 μg/m^3 during November). Nitrogen and sulfur dioxides (SO_2 and NO_2) outstrip NEQS during entrance of heavy traffic in the city at 11 pm. CO remains within NEQS on most of the spots in the city. SO_2 remains relatively high in the industrial area (may be due to use of diesel and coal), while CO remains relatively high on roadside (may be due to use of petrol as fuel by most of the automobiles). High emission factors are observed for NO_2, SO_2, PM_{10} and $PM_{2.5}$ emissions from diesel vehicles; on the other hand, high emission factors for CO is observed for gasoline vehicles.

The modeled results have shown significant correlation (r-value >0.5) with observed (monitored) results. It is obvious that whenever a background air quality monitoring station is located outside the city, it would show low pollution level as compared to a city center air quality monitoring station. In this case the designated station at Town Hall building at Mall road (as background air quality monitoring station) is located in polluted area, the modeled results for relatively clean areas like Gulberg road may show less correlation (r-value for NOx is 0.42). The modeling results are better for those streets which are located in relatively polluted areas and are near to the background urban air quality monitoring station e.g. the r-value for, NOx, CO and SO_2 are 0.92, 0.88 and 0.92 respectively.

There is need to install a background station out side the city premisis to compare the pollution load in and outside the city and model the street pollution in a more reliable way. A complete picture traffic count of different other roads can also be obtained through installation of traffic monitoring technology on other roads, which would further be helpful in modeling of road pollution on the roads.

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