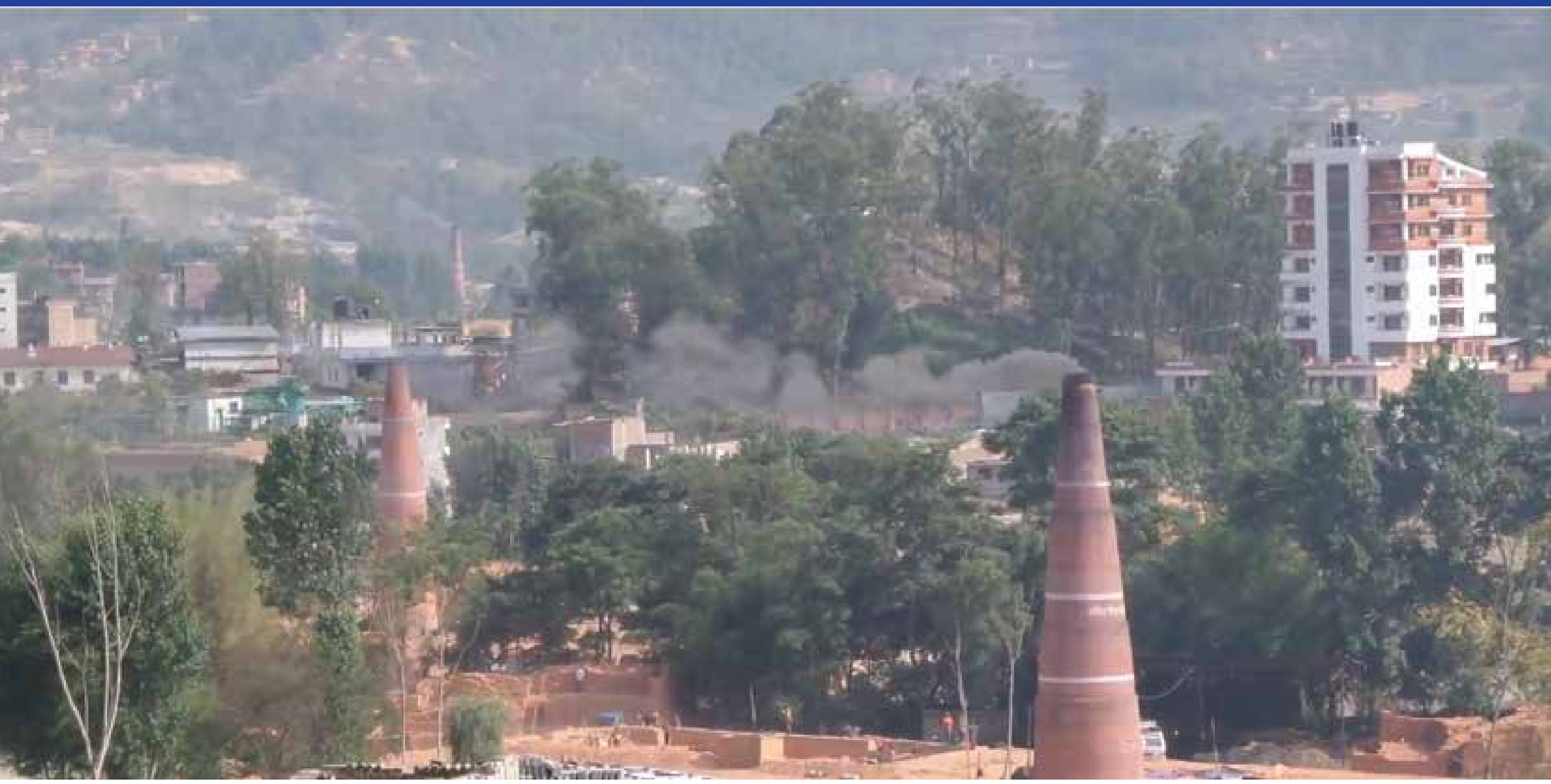
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley

2015



Government of Nepal

Nepal Health Research Council

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Dr. Khem Bahadur Karki
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ACRONYMS

ACF	Autocorrelation Function
AM	Arithmetic Mean / Before Noon/Ante Meridiem
ARI	Acute Respiratory Infection
AT	Atmospheric Temperature
ß	Parameter Estimate
CV	Coefficient of Variation
CA	Cancer
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
DG	Diesel Generator
df	Degrees of Freedom
DoHS	Department of Health Services
EBD	Environmental Burden of Diseases
GAM	Generalized Additive Model
Geo	Geometric
GLM	Generalized Linear Model
HCI	Health Care Institution
KMC	Kathmandu Medical College
KS	Kolmogorov Smirnov
KTM	Kathmandu
LARI	Lower Acute Respiratory Infection
m	Meter
mg	Milligram
mm	Millimeter
MoHP	Ministry of Health and Population
N	Sample Size
NAAQS	Nepal Ambient Air Quality Standard
NHRC	Nepal Health Research Council
NMC	Nepal Medical College
NO_2	Nitrogen Dioxide
PM	Particulate Matter / Afternoon/Post Meridiem
$PM_{2.5}$	Particulate Matter with Aerodynamic Size less than 2.5 Microns
q-q	Quantile - Quantile
RH	Relative Humidity
RC	Recoded
RR	Relative Risk

SD	Standard Deviation
Sig	Significant
Std	Standard
TUTH	Tribhuvan University Teaching Hospital
UARI	Upper Acute Respiratory Infection
UNEP	United Nations Environment Programme
µg	Microgram
VIF	Variance Inflation Factor
Z	Standardized value

EXECUTIVE SUMMARY

Introduction

Pollution induced respiratory diseases have increased worldwide, a phenomenon that can be largely attributed to environmental effects. Among environmental factors, air pollution is identified to be a major threat to human health. Excessive exposure and inhalation of Particulate Matter less than 2.5 micrometers in diameter ($PM_{2.5}$), Carbon monoxide (CO) and Nitrogen dioxide (NO_2) can lead to upper and lower respiratory tract infections in children and can cause chronic health impacts in adults. Major cities of Nepal are now considered unhealthy due to increase in population, unplanned urbanization, and industrial and vehicular emissions and so on. Beside these factors, improper implementation of policies and programs are also driving forces contributing to increase air pollution in Kathmandu Valley. Despite this situation, continuous air quality monitoring is not in place except some scanty reports from some places for some specific period of time. In order to find out a year round situation of the ambient air pollution in Kathmandu valley, Nepal Health Research Council (NHRC) conducted a '*Situation Analysis of the Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley,2015'* from 13 February 2014- 12 February 2015.

Methodology

The study was designed based upon ecological time series, and expected to link respiratory disorders with ambient air pollution through calculation of relative risks and attributable fractions. Three environmental pollutants: $PM_{2.5}$, CO, and NO_2 were measured in this study along with collection of morbidity and mortality data from major hospitals in Kathmandu Valley. Under this study, three monitoring stations were established at three different locations in Kathmandu Valley: Putalishadak in Kathmandu, Mahalaxmisthan in Lalitpur and Bhimsensthan-Jagati in Bhaktapur. At each study site, daily monitoring was conducted for twelve months from 1 Falgun 2070 to 29 Magh 2071 (13 February 2014 to 12 February 2015) to find out the mean and peak concentrations of $PM_{2.5}$ and CO, and the mean concentration of NO_2, A Nephelometer E-sampler and ToxieRae CO and NO_2 sampler were used to monitor $PM_{2.5}$, CO and NO_2. Daily inpatient data related to respiratory health conditions were collected for all age groups throughout the year. Data were analyzed with respect to ambient air quality and changes in respiratory disease outcomes. Generalized linear modeling was used to associate health effects with multiple ambient air pollution parameters ($PM_{2.5}$, CO and NO_2), accounting for various confounding variables such as temperature, humidity, rainfall, season, and day of the week. Responses considered were hospital inpatient counts of age and address specific respiratory illness hospitalizations including COPD, ARI and pneumonia. Moreover, models were screened with different model adequacy measures, namely goodness of fit, normality, heteroscedasticity, multicollinearity, autocorrelation and outliers. In addition, burden of respiratory disorders attributable to ambient air pollution was also estimated for Kathmandu Valley.

Findings

A year continuous monitoring of ambient $PM_{2.5}$, CO and NO_2 in Kathmandu Valley showed that the valley's ambient air (57.6% for $PM_{2.5}$ and 56.4% for NO_2) has exceeded the daily National Ambient Air Quality Standards (NAAQS) for the majority of the days of monitoring, but in the case of CO, only a single day exceeded the national standard (using 8 hour averages). Daily averages of $PM_{2.5}$ are 3-5 times higher than the national standard of 40µg/m^3. Moreover, concentrations of NO_2 in ambient air are also found to be high, with several very high spikes monitored above 1000 µg/m^3, which is around 12 times higher than 24-hour national standard of 80µg/m^3. Station-wise results revealed that Kathmandu is more polluted with $PM_{2.5}$ and CO throughout the year when compared to Lalitpur and Bhaktapur.

Seasonal and monthly variations showed that winter and spring months are heavily polluted with ambient $PM_{2.5}$ levels. This indicates a negative association of fine particulate pollution with meteorological variables like temperature, humidity and rainfall. However, with CO this is not found to be the case, which remained at similar levels throughout the year. The level of NO_2 shows similar trend to that of $PM_{2.5}$. We found definite patterns of cyclic variations in pollution levels for all the three pollutants monitored in the 24 hour cycle.

$PM_{2.5}$ Pattern

$PM_{2.5}$ levels are the lowest (below 40 µg/m^3) during post-midnight and before dawn (12-5 AM). The level gradually increases throughout the morning and peaks at 87 µg/m^3 during 8-9 AM. Then gradually decreases and reaches lowest value (31 µg/m^3) during the afternoon (2-3 PM). Thereafter, the level gradually increases again and reaches maximum (59 µg/m^3) at 8-9 PM before gradually decreasing again late at night. The gradual increase in pollution in morning may be partly due to an increase in traffic indicating a possibility of morning walkers likely to be affected by high level $PM_{2.5}$ exposure.

CO Pattern

Hourly average figures of CO found at very low levels after midnight and before dawn (less than 200 µg/m^3), which start to increase during early morning (5-6 AM) and reach around 635 µg/m^3 during 10-11 AM. The level remains relatively high during the day until 2-3 PM (500-670 µg/m^3) then decrease to 400 µg/m^3 around 4-5 PM. The level again increases to around 725 during 7-8 PM and decrease thereafter from midnight (189 µg/m^3) to the dawn (118 µg/m^3). Nonetheless, the values are well below the 8 hour NAAQS of 10000 µg/m^3.

NO_2 Pattern

The hourly NO_2 average figures show cyclic variation similar to $PM_{2.5.}$ The figures are much higher than the 24-hour recommended standard of 80 µg/m^3. Relatively, the levels are on the lower side after midnight and before dawn (160-170 µg/m^3) and start rising in the early morning

(5-6 AM). The level rise to around 270 μg/m^3 during 9-10 AM and start to decrease gradually during day time, reaching 140 μg/m^3 during 4-6 PM, which then rises to around 180 μg/m^3 during 6-9 PM and then starts to decrease until midnight (150 μg/m^3).

Ambient air pollution in load shedding period

It is found that $PM_{2.5}$ pollution in the ambient air is 33.34% higher during a power outage period compared to normal times when electricity is available. The higher levels of $PM_{2.5}$ during power outage could be due to the use of generators or other means of fuels which pollute the ambient air with particulate matters. All stations show higher ambient $PM_{2.5}$ levels during power outage hours. The ratio of $PM_{2.5}$ for power outage hours compared to other times is the highest (1.36) in Lalitpur and the lowest in Kathmandu (1.28).

Respiratory health effects

Analysis of respiratory health effects and subsequent statistical modeling was used in 11,300 inpatient records of the fiscal year 2071/72 (2014/15) from thirteen major hospitals of Kathmandu Valley. Among the respiratory diseases, COPD 39.49%, pneumonia 29.13% and ARI excluding pneumonia 15.33% were the leading causes of inpatient hospitalizations in those hospitals. Comparative assessment among different age groups shows that children (0-9) and aged persons (50 and above) years are the most vulnerable groups to respiratory disorders, with 25.5% patients being children and around 55% being aged persons. Gender-wise, male inpatients were slightly more common (51.3 %) than female inpatients. There is a steady decrease in seasonal trend from spring to winter for total cases of respiratory hospitalization. $PM_{2.5}$ is positively correlated with most of the hospitalizations considered, whereas monthly means of CO and NO_2 are negatively associated with respiratory hospitalizations, barring a few exceptions for NO_2. Temperature is found to be positively associated with respiratory diseases except for COPD, whereas rainfall and relative humidity are found to be negatively associated with respiratory hospitalizations. It must be noted that most of the correlations are not statistically significant, indicating a necessity of further investigations.

Morbidity effects of predictors

Effects of $PM_{2.5}$

Around 1-1.4% increase in respiratory hospitalizations (same day lag effects), 1-2% increase in COPD hospitalizations (same day lag effects), 2-2.8% increase in ARI hospitalizations (7 day geometric and 2 day mean effects), 3.2-4.7% in pneumonia hospitalizations (7 day arithmetic and geometric lag effects) and 0.8-3% increase in respiratory hospitalizations for aged persons (50 and above) are detected per 10 μg/m^3 rise in $PM_{2.5}$. Conversely, $PM_{2.5}$ is found to be a statistically insignificant predictor for respiratory hospitalizations when the sub-population comprising children and adolescents aged 19 and less is considered which is rather contrasting result to that of other models developed.

Effects of CO

Varied effects of ambient CO are detected for different response models. It is found to be an insignificant predictor for respiratory hospitalizations including for children, adolescents and COPD hospitalizations. It is found to be significant but negatively associated with ARI hospitalizations with 11.6% decrease in hospitalization per 1 mg/m^3 rise in CO (7 day lag effects), and 10.2-13.2% decrease in pneumonia hospitalizations (7 day arithmetic and geometric lags) per 1 mg /m^3 rise in CO. Only in cases of respiratory hospitalizations of aged persons with age 50 and over, CO is found to be positively associated with a 5.8-5.9% increase in respiratory hospitalizations (same day lag effects) per 1 mg/m^3 rise in CO.

Effects of NO_2

NO_2 also showed varied effects depending upon the response variable. No evidence of its effects was revealed for respiratory admissions for any age group. It showed a significant but negative relationship with ARI, pneumonia and respiratory hospitalizations for children and adolescents, with 23-30% decrease in ARI hospitalizations (7 day arithmetic and geometric decays), 22.5% decrease in pneumonia hospitalizations (7 day arithmetic decay) and 45-57% decrease in respiratory hospitalization of children and adolescents (7 day arithmetic decay) per 1 mg/m^3 rise in ambient NO_2. However, NO_2 showed a significant and positive correlation with COPD hospitalizations (2 day and 7 day lag effects) and respiratory hospitalizations of aged persons with age 50 and above (2 day mean effect), with varied effects of 9-31% increase in COPD hospitalizations and 7-10% increase in respiratory hospitalizations of people aged 50 and above per 1 mg/m^3 rise in $NO_{2.}$

Effects of temperature

An increase of 0.65-1% in respiratory hospitalizations (same day lag effect), 1.4-2.4% in ARI hospitalizations (7 day mean and 7 day geometric lag effects), 1.4-2.2% in pneumonia hospitalizations (7 day arithmetic and 7 day geometric lag effects), and 0.7% in respiratory hospitalizations (same day effect) for people with age 50 and above (Kathmandu residents only) was detected per 1^0 Celsius rise in temperature. It is found to be statistically insignificant for COPD and respiratory hospitalizations of children and adolescents.

Effects of relative humidity

Relative humidity is associated with 0.6-1.6% decrease in respiratory hospitalizations (same day effect), 1.9-3.6% decrease in COPD hospitalizations, and 1.6-3% decrease in respiratory hospitalizations for the 50 and above population per 1% increase in relative humidity, respectively. It is found to be insignificant with regards to ARI and pneumonia hospitalizations.

Effects of rainfall

Rainfall is associated with 0.3% decrease in respiratory hospitalizations (same day effect), 0.5-0.7% decrease in COPD hospitalizations (same day effect), 1-1.3% decrease in ARI hospitalizations (autocorrelation ignored models), 1.6-2.2% decrease in pneumonia hospitalizations (autocorrelation ignored models with 7 day mean and geometric decay), 1% decrease in respiratory hospitalizations of children and adolescents (Kathmandu Valley residents with 7 day arithmetic decay) and 0.4-0.6% decrease in respiratory hospitalizations of aged 50 and above (except in autoregressive Kathmandu resident model with 2 days mean effect) per 1mm increase in rainfall, respectively. It is found to be insignificant with regards to pneumonia hospitalizations.

Seasonal effects

Seasonal effects are not included in most of the models because of their statistical insignificance or multicollinearity problems with temperature. However, in the case of respiratory hospitalizations for children and adolescents, they are found to be significant and better predictors than temperature. Pre-monsoon and winter seasons showed lower respiratory hospitalizations, with 8.6-13.9% and 7.3-11.2% decreases, respectively.

Day of week effect (Saturday)

Interestingly, non-Saturdays (i.e. remaining days of week) showed higher hospitalizations compared to Saturdays in all the 24 morbidity models developed, which may be attributed to various reasons. Increases of 40-50% in respiratory hospitalizations, 48-55% in COPD hospitalizations, 37-42% in ARI hospitalizations, 43-48% in pneumonia hospitalizations, 28-44% in respiratory hospitalizations for children and adolescents and 45-52% in respiratory hospitalizations for people aged 50 and above were detected for non-Saturdays.

Mortality effect

The developed GLM shows that a weeklong geometric distributed lag effect of $PM_{2.5}$ (positive) and NO_2 (negative), and same day lag effects of CO (positive) and temperature (positive) are statistically significant in predicting all-cause mortality. Autocorrelation was not found to be significant in the developed model, and hence autoregressive model was not developed.

$PM_{2.5}$ is associated with a 3.7% rise in mortality per 10 $\mu g/m^3$ rise in $PM_{2.5}$ (7 day geometric lag effect); CO is associated with a 0.15-0.7% rise in mortality per 10 $\mu g/m^3$ rise in CO level (same day effect), temperature is associated with a 1.4% rise in mortality per 1^0 Celsius rise in temperature (same day effect) and non-Saturdays are associated with a 30% rise in mortality compared to Saturdays.

Assessment of EBD due to ambient air pollution

Attributable fraction ranges between 0.05 to 0.15, the lowest being for all respiratory conditions and highest being for pneumonia, with corresponding burdens of 547 and 509 hospital cases attributable to ambient $PM_{2.5}$ for the study period (2070/71). The disease burdens attributable to $PM_{2.5}$ for COPD, ARI and respiratory admissions for persons aged 50 and above are 279 (AF=0.06), 479 (AF=0.10) and 534 (AF=0.09) hospitalizations for the monitored year respectively. Similarly, the attributable hospital burdens of ambient NO_2 are 238 (AF=0.05) and 101 (AF=0.02) for COPD and respiratory hospitalizations (aged 50 and above), respectively, for the monitored year.

Conclusion

A year monitoring of ambient air quality parameters of Kathmandu Valley showed that ambient air appears to be polluted with high levels of $PM_{2.5}$ and NO_2. Two of the pollutants ($PM_{2.5}$ and NO_2) monitored exceeded 24-hour averages of the daily NAAQS for more than half of the days monitored throughout the year. Daily averages of $PM_{2.5}$ were higher than the NAAQS, which significant effect on respiratory morbidity mainly on COPD and pneumonia. Station-wise results revealed that Putalisadak in Kathmandu is the most polluted with levels of $PM_{2.5}$ and CO being higher for the majority of days monitored over the year.

Observing the $PM_{2.5,}$ CO and NO_2 variation, it was found that the pollution level remained the lowest during post-midnight and before dawn which gradually increased throughout the morning and reached a peak around 8-9 AM. This may pose health threats to morning walkers in Kathmandu Valley. Government should enforce policies for prevention and control of air pollution in Kathmandu Valley.

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CHAPTER I
INTRODUCTION

1.1 Background

The world is witnessing a rise in the prevalence of allergic and non-communicable diseases (2). Environmental and behavioral factors are considered as major contributing risk factors for these diseases. In particular, air pollution is identified to be a major threat to childhood and adult health (3). Globally, 3.7 million deaths are attributed to ambient air pollution (AAP) per year. About 88% of these deaths occur in low- and middle-income (LMI) countries, which represent 82% of the world's population. The Western Pacific and South East Asia bear most of the burden, with 1.67 million and 936,000 deaths per year respectively (4). It is also estimated that outdoor air pollution is responsible for approximately 1.4% of total mortality, 0.5% of all disability-adjusted life years (DALYs) and 2% of all cardiopulmonary disease (5). Particulate matter less than 10 µm and 2.5 µm in diameter, carbon monoxide, nitrogen oxide etc. are characterized as toxic pollutants in the ambient environment and hazardous for the exposed population (5). It is known that smaller inhaled particulates produce more inflammation than larger ones. Respiratory symptoms and airway inflammation are positively correlated with ultra-fine particle (UFP) content in exhaled breath condensate (EBC) of symptomatic children (2). Exposure to carbon monoxide (CO) is associated with effects ranging from more subtle cardiovascular and neurobehavioral effects at low concentrations to unconsciousness and death after acute or chronic exposure to higher concentrations of CO. The symptoms, signs, and prognosis of acute CO poisoning correlate poorly with the level of carboxyhemoglobin (COHb) in the blood. The early symptoms of headache, dizziness, weakness, nausea, confusion, disorientation, and visual disturbances are associated with carbon monoxide concentration (6). Furthermore, NOx is a toxic environmental pollutant that contributes to a wide range of environmental effects, including the formation of acid rain, with resulting health impacts and contributions to regional haze, eutrophication of aquatic ecosystems, and elevated ozone concentrations, with resulting impacts on health and agriculture. It is a corrosive chemical which attacks the respiratory tract, increasing susceptibility to infection, and also produces skin cancer and birth effects (7). Hence, particulate matter (PM), CO and NO_2 pollution in major cities of developing countries including Nepal is considered as major risk factors of environmental burden of diseases. Acute respiratory tract infection (ARTI) has been one of the most important health problems in Nepal until today (8). Air pollution is a major contributing risk factor for ARTI (9), and Kathmandu, the capital of Nepal, is considered as major polluted city in Asia (10). Some data show that particulate matter levels in ambient air of Kathmandu are higher than Nepal's national ambient air quality standards (NAAQS) 2012(1, 11)

Rapid urbanization, industrialization, maintenance and widening of roads, poor maintenance of vehicles and lack of public awareness are all responsible for the deteriorating ambient air quality in major cities of Nepal. In addition, topography, climate and the atmospheric structure of Kathmandu Valley are major contributing factors. Anthropogenic activities such as the haphazard growth of vehicle numbers, massive use of fossil fuels in vehicles, use of fossil and solid fuels in cooking, inefficient indoor heating devices, use of coal in brick kilns, and re-suspension of road dust all contribute to the problem. Though the natural landscape of the valley will remain a challenge to counter air pollution, taking some action towards mitigating anthropogenic sources could solve the problem at an individual and policy level. From this perspective, we need to generate data on the level of pollution to guide evidence-based policy. The Ministry of Science, Technology and Environment initiated and installed air quality monitoring systems in 2001 at six locations in Kathmandu Valley, but these stations have been nonfunctional since 2006. Therefore, we do not have current information about ambient air pollution ($PM_{2.5}$, NO_2, CO etc.) in Kathmandu Valley. Medical records from health institutions of major cities, however, have shown that air pollution-sensitive diseases are on rise. To explore association with respiratory ailments, investigation of ambient air pollution levels through monitoring stations may be useful. Measurements of fine particles ($PM_{2.5}$), and gaseous pollutants like carbon monoxide (CO) and nitrogen dioxide (NO_2) could help to identify sources of air pollution in the valley, and thereby identify areas for intervention.

1.2 Statement of the problem and rationale / Justification

Nowadays, ambient air pollution is being seen as one of the major public health problems in major cities of Nepal. Kathmandu Valley is particularly sensitive because of various attributing factors like topography, atmospheric climate, brick kilns and transportation (12). Due to its distinctive topographical features, high levels of pollutant emissions make the valley vulnerable to air pollution. Its bowl-shaped topography restricts wind movement and retains pollutants in the atmosphere. This is especially problematic during the winter season (November-February) when thermal inversion occurs in the valley during late night and early morning. Cold air flowing down from the mountains are trapped under a layer of warmer air which acts as a lid. As a result, the pollutants are trapped close to the ground for extended periods of time (10)

Another major contributing factor to air pollution in the Valley is due to unmanaged transport system. A report from the transport authority showed a significant rise in the number of vehicles in the country over recent years with increased unplanned urbanization. For example, the total number of vehicles in 1989-1990 was 76,378, and this figure increased to 1,348,995 in 2011-2012. These numbers reveal that there has been a greater than 15-fold increases in the number of vehicles since 1989-1990 (8). The annual growth rate of vehicles in the Bagmati zone for the last ten years has been 12%. The Bagmati Zone accounts for 46.2% of total vehicles in the country (8).

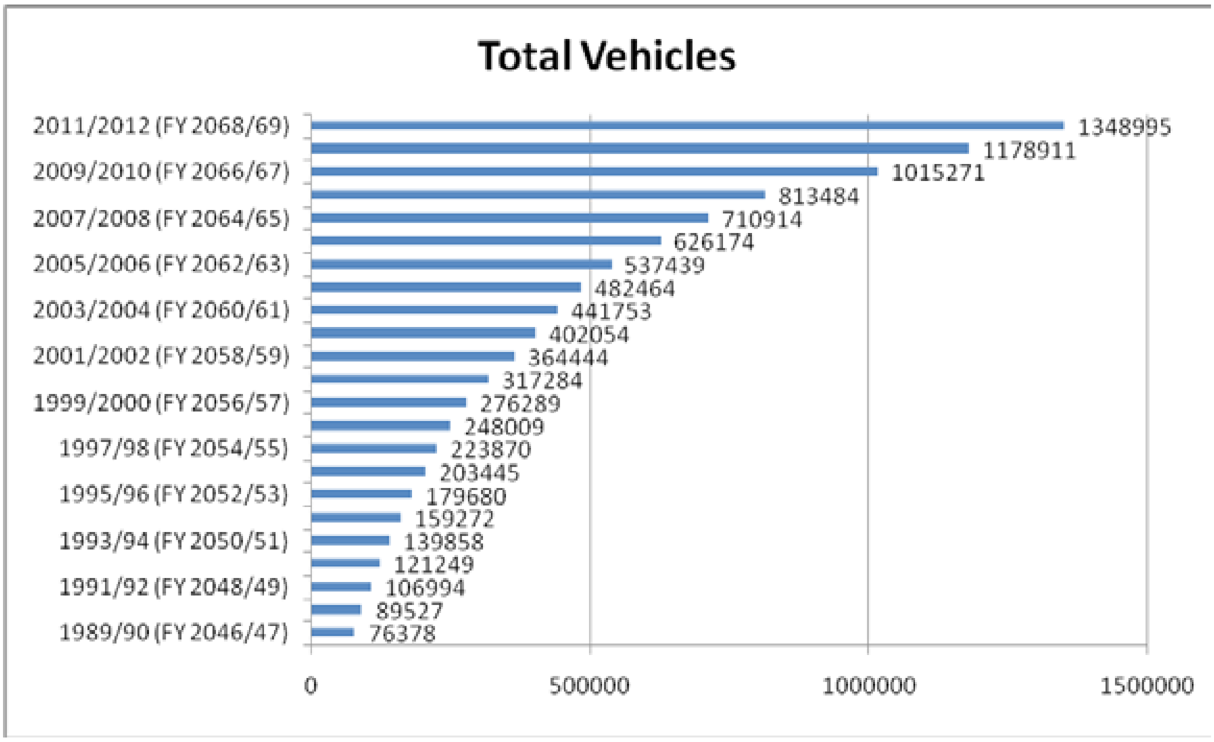


Figure 1: Vehicles growth in Nepal (1989-2012)

Source: Department of Transport Management

Rapid growth of vehicles is not only creating air pollution problems, but also equally creating a problem in its management. Most of the policy provisions and control mechanisms for vehicle emissions are focused on cleaner fuel and emission standards for new vehicles, but it is important that these policy provisions focus equally on 'in use vehicles', which are running on the streets for many years. The percentage of high emission vehicles increases with vehicle age, and it is reported that 30% of five year-old vehicles emit excessive pollution. Lack of strong legal documentation and clear provisions are also causes of the problem. For example, the Ministry of Science, Technology and Environment (MoSTE) is responsible for the development of various standards and laws related to pollution, and for setting vehicle emission standards for the entire nation. However, the Vehicle Inspection and Maintenance (I/M) program is handled by the Department of Transport Management (DoTM) alone, which is creating problems/ constraints in the technical and decision-making process in some cases. For instance, MoSTE has upgraded the Nepal Mass Vehicle Emission Standards to match the Euro III standards, yet the Pollution Control Division is still using the Euro I 'In-Use Vehicle' standards. Vehicular emissions constitute about 38% of the total pollution in Kathmandu Valley alone. Furthermore, the transport sector is responsible for 63% of particulate matter (PM) in the valley (13, 14).

Brick kiln is another major source of air pollution in the valley. According to 'All Nepal Brick Kiln Association', there are around 104 brick kilns operating in Kathmandu Valley only. These kilns are operating mostly during the dry season which increases the level of pollution significantly. It is affecting mostly the peri-urban, urban communities of Lalitpur and Bhaktapur.

Regular scheduled power outage poses an additional burden for clean air protection system in Kathmandu. The number of diesel generator (DG) sets as an alternative source of electricity in the industrial, commercial and non-commercial sectors have contributed in increasing air pollution in the valley.

Around 66.5% of the total diesel sold in Kathmandu valley during 2012-13 was used for diesel power generation. It is estimated that nearly 400 tons of PM_{10} is emitted. The commercial sector (hotels, restaurants, shopping malls, banks etc.) has been found to be the largest source of emissions from diesel power generation, accounting for around 77% of total PM_{10} emissions (15). The emissions from diesel generators are especially high during the dry season when power outage is at its peak. Together, these factors constitute the current main contributing factors to the air pollution scenario of Kathmandu valley.

The government of Nepal monitored PM_{10} air quality at six stations in Kathmandu valley between 2001 and 2006. Monthly average air quality was observed to be many times higher than Nepal and WHO's air quality standards. Additionally, coefficients of PM_{10} were found to be statistically significant for respiratory morbidity and COPD morbidity at the 95% confidence level, though insignificant for other diseases (16). Until now though, levels of $PM_{2.5}$, NO_X and CO have not been monitored, and these are higher risk particulate pollutants for respiratory function than PM_{10}. Therefore, Nepal Health Research Council (NHRC) initiated the current study to assess the situation of ambient air quality within Kathmandu Valley.

This study has timely investigated the respiratory health status of the exposed population in selected areas. Even though comprehensive data is not available regarding ambient air particulate levels in Nepal, air pollutants are certainly detrimental and the adverse impacts on public health in Kathmandu Valley and other major cities of Nepal are on rise. This study has addressed the need for information on the effects of air pollution on health in this region, and provide locally-gathered evidence to support actions by the government to control particulate emissions.

1.3 Research objectives

General objective

- Situation analysis of the ambient air pollution and respiratory disorders of the exposed population in Kathmandu Valley

Specific objectives

- To monitor the major pollutant constituents of ambient air, namely $PM_{2.5}$, NO_2 and CO
- To assess the temporal variations of ambient pollutants, namely $PM_{2.5}$, NO_2 and CO
- To assess the possible link between outdoor air pollutants, namely $PM_{2.5}$, NO_2 and CO, and changes in number of cases of respiratory morbidity (COPD, pneumonia, asthma, bronchitis, ARI) and all-cause mortality
- To calculate the environmental burden of disease of respiratory morbidity and all-cause mortality that can be attributed to ambient air pollution

CHAPTER II
METHODOLOGY

2.1 Study site and its justification

Kathmandu Valley was chosen as the study site owing to its high population density, high number of vehicles and existence of factories such as brick kilns. In addition, the bowl shaped topography of Kathmandu Valley contributes to air pollution retention. Based on reference points from the outcome of the annual averages of PM_{10} at different monitoring sites in Kathmandu Valley studied by MoSTE in 2007, three stations were decided to be included as pollution monitoring stations at Putalisadak in Kathmandu (location: <9 meter height and approximately 9 meter from roadside), Mahalaxmisthan at Lalitpur (location: <9 meter height and approximately 300 meter from roadside) and Siddhi Memorial Hospital, Bhimsensthan-Jagati at Bhaktapur (location: <9 meter height and approximately 500 meters from roadside). For the purpose of gathering hospital data for respiratory health effects assessment, major government hospitals as well as some private hospitals in the valley were considered for the study. Major hospitals, namely Kanti Children Hospital, Bir Hospital, Tribhuwan University Teaching Hospital, Patan Hospital, Nepal Medical College Teaching Hospital, Kathmandu Medical College Teaching Hospital, Om Hospital and Research Center, Civil Service Hospital, Ishan Children and Women's Hospital, KMC Duwakot Hospital, B & B Hospital, and Bhaktapur District Hospital were included for collection of relevant hospital data related to mortality and morbidity.

2.2 Study type

The study was designed based upon ecological time series, in which air pollution parameters ($PM_{2.5}$, NO_2 and CO), meteorological parameters and data on other confounders such as seasonality, day of week and corresponding respiratory health data were collected.

2.3 Study design

The ecological time series study was designed which is expected to link respiratory disorders with ambient air pollution through calculation of relative risks, attributable fractions and environmental burden of disease attributable to ambient air pollution, specifically that of $PM_{2.5}$.

2.4 Study variables

Air quality parameters: Levels of $PM_{2.5}$, CO, NO_2

Climatic parameters: Temperature, humidity, precipitation;

Health effect variables: Respiratory mortality and morbidity e.g. ARI, bronchitis and asthma; other confounders: seasonality, day of week.

2.5 Study population and study unit

Population of Kathmandu valley was study population and people who got admitted in hospitals with respiratory complaints as inpatients were study unit.

2.6 Sampling method / Technique

Urban centers of Kathmandu, Lalitpur and Bhaktapur district were selected for the study. From these three districts, Putalishadak in Kathmandu, Mahalaxmisthan in Lalitpur and Bhimsensthan-Jagati in Bhaktapur were selected for the current study. At each study site, daily monitoring of $PM_{2.5}$, CO and NO_2 was conducted for twelve months from 1 Falgun 2070 to 30 Magh 2071 (13 February 2014 to 12 February 2015). Air quality monitoring was conducted to establish the mean and peak concentrations of $PM_{2.5}$ and CO and mean concentration of NO_2. In addition, data on confounding variables related to meteorology, such as temperature, humidity, wind speed, wind direction and precipitation were collected from the Department of Hydrology and Metrology, Government of Nepal. During the study period, hospitals were also selected purposively, and data on ARI, bronchitis, COPD, asthma and other respiratory ailments were collected throughout the year. During the data collection phase, information on patients diagnosed with respiratory problems, and related mortality associated with respiratory complaints were collected from each hospital/health center. This information was used to identify the risk of respiratory problems associated with the air pollution.

In order to calculate the expected disease burden, secondary data from district health/public health offices were also utilized. Additionally, hospital data on total disease burden for a specified period (such as a year) was compiled if required.

Table 1 : Assessment of ambient air pollution and respiratory health parameters

<table>
<tr><th>Measurement</th><th>Pollutant</th><th>Pollution measurements</th><th>Compiling hospital data</th></tr>
<tr><td>Outdoor</td><td>$PM_{2.5}$</td><td>3 clusters * 24 hours * 12 months of daily monitoring (around 365 days)</td><td rowspan="3">Assessment of various respiratory diseases, namely chronic obstructive pulmonary disease (COPD), acute respiratory diseases including upper and lower respiratory infections (tonsillitis, sinusitis, otitis media, common cold and pneumonia, etc.), bronchitis, asthma, respiratory symptoms and other diseases like pleural effusion, tuberculosis, CA lungs, etc.</td></tr>
<tr><td>Outdoor</td><td>NO_2</td><td>3 clusters * 24 hours * 12 months of daily monitoring (around 365 days)</td></tr>
<tr><td>Outdoor</td><td>CO</td><td>3 clusters * 24 hours * 12 months of daily monitoring (around 365 days)</td></tr>
</table>

2.7 Data collection technique/ Tools

Air quality monitoring: air quality monitoring was conducted using standard air quality monitoring devices as described below.

- $PM_{2.5}$ data were collected using Nephelometer-like dust track or equivalent monitor.
- CO data were collected using HOBO CO monitor or equivalent.
- NO_2 data were collected using NO_2 passive sampler.

2.7.1 Air pollution monitoring

List of Equipment to Measure Air Pollution

$PM_{2.5}$: E-Sampler Continuous Ambient Particulate Matter Monitor by Met One, U.S.A**.**

CO: QRAE II Continuous Multi-gas Detector Diffusion Monitor by RAE System, USA

NO_2: QRAE II Continuous Multi-gas Detector Diffusion Monitor by RAE System, USA

Monitoring Methods

$PM_{2.5}$

We used the E-SAMPLER Aerosol Monitor to measure $PM_{2.5}$ levels in Kathmandu Valley. The E-SAMPLER is a light-scatter real time aerosol monitor (nephelometer), which automatically measures and records real-time airborne $PM_{2.5}$ (and also PM_{10}) using the principle of forward laser light scatter. It has a sensitivity of 1 µg/m3. In addition, the E-SAMPLER has a built-in 47 mm filter sampler which was used to collect the particulate matter for subsequent gravimetric mass. The gravimetric mass was used to determine a gravimetric K-factor (slope multiplier) to correct the E-SAMPLER real-time signal to match the local particulate type. Thus, the E-SAMPLER combines the excellent real-time response of a nephelometer with the accuracy and traceability of a low flow manual gravimetric sampler.

In principle, sampled air is drawn into the detection zone of the E-SAMPLER and then passes through the laser optical module, where particulates in the sampled air stream scatter the laser light according to their reflective and refractive properties. This scattered light is collected onto a photodiode detector at a near-forward angle, and the resulting electronic signal is processed to determine a continuous, real-time measurement of airborne particulate mass concentrations. The E-SAMPLER can run for longer periods of time using external 12 volt, 110 amp-hour deep cycle batteries.

CO & NO_2

For gaseous pollutants like CO and NO_2 we used QRAE II Continuous Multi-gas Detector Diffusion Monitors developed by RAE System, USA. These monitors use the patented SPEO2 electrochemical sensors usually two electrodes to measure pollutants using passive diffusion method. Pollutants are oxidized in the electrochemical sensors and give real time data/results. The results could be downloaded using ProRAE Studio software. These instruments require minimal power supply and can be operated with Lithium-ion or alkaline battery. These samplers are water and dust resistant and can be left for an extended period of time outdoors.

2.7.2 Quality control of air quality monitoring instruments

P.M $_{2.5}$

- Monitors work using a laser optical module, which is known to be robust.
- Monitors were operated through electricity and dry gel cell battery so pollution from generators was avoided.
- Monitors were factory calibrated in the US six months before deployment, with valid up to 2 years.
- It also has a self-calibration system and calibrates every 24 hours.
- It has a heated inlet assembly Included, which absorbs moisture in dust particles before measurement.
- 72 hours' data collection in 47mm glass filter has been completed with laser measurement to determine K factor to evaluate the monitoring reading time signal to match local particulates.
- 47mm glass filters were weighed on a 6-digit balance in the US.

CO and NO_X

- Factory calibrated in the US six months beforehand, for 2 years usage period.
- Weekly calibration was carried out in Ziploc bag (0 air) after weekly data download.

2.7.3 Health data collection technique and tools

Health indicator assessment

Medically diagnosed cases of ARI, bronchitis and asthma were assessed for up to one year during the pollutants emission monitoring period (Falgun 2070 to Magh 2071) from the selected hospitals.

2.7.4 Validity and reliability of the study tools

Air quality monitoring instruments were calibrated to an internationally accepted standard as described in 2.7.2. Daily monitored air quality data were transferred from monitoring instruments and stored in a computer database. Monitoring stations were continuously observed, frequently by an expert and also by research team members. Data collection sheets were prepared and reviewed by experts. Data collectors were trained in air quality monitoring and health data collection processes. Data collection sheets were translated to Nepali and then again translated to English.

2. 8 Meteorological data

Data on temperature, humidity and precipitation were included in the time series models as confounding variables along with air pollution data to assess short term health effects due to outdoor air pollution. Consequently, information on these variables were considered using exposure-response modeling. Time series and area-specific data were required for exposure-response relationship modeling. The targeted secondary sources of meteorological data were obtained from the Department of Meteorology.

2.9 Exposure-response modeling based upon time series data

Generalized linear models (GLMs) with log link functions were used for exposure-response modeling. This type of model is suitable for air pollution and health impact assessment based upon time series data, and has been used in this way in past studies. The model can be stated as follows.

$$Log_e(\mu) = \beta_0 + \sum \beta_i x_i \tag{1}$$

where μ is the mean response of daily hospitalization counts/mortality counts; $\beta_i^{'}s$ are the unknown parametric terms; $x_i^{'}s$ are the explanatory variables with parametric coefficients including that of daily air pollutant concentrations ($PM_{2.5}$, NO_X and CO) and confounders.. The model is characterized by the following features:

- Multiple pollutant effects so that data can be fitted as a GLM Distributed lag effects with consideration of different types of lags
- Use of potential confounders, namely metrological parameters, seasonality and day of week
- Use of autoregressive terms wherever necessary to address autocorrelation problem.

2.9.1 Computation of Environmental Burden of Disease (EBD)

Calculation of EBD constitutes the following steps.

- **Estimation of relative risks (STEP 1)**

The estimated β coefficients obtained from exposure-response modeling were used to calculate relative risks associated with different ranges of pollution concentrations. For instance, to calculate the total premature mortality/morbidity or the number of deaths/hospitalizations attributable to existing air pollution ($PM_{2.5}$ concentration), the following expression was used.

$$RR_k = e^{\hat{\beta}_k(C_k - T_k)} \qquad (2)$$

Where RR_k is the relative risk associated with the k^{th} pollutant when its concentration is raised from the threshold value (T_k) below which there is no detectable health effects to a higher concentration level (C_k) where health effects are detectable.

- **Calculation of attributable fraction (STEP 2)**

After calculating the relative risk of specified pollutants in the ambient air, attributable fractions (AF) were calculated using the following equation.

$$AF = \frac{\left(\sum P_i RR_i\right) - 1}{\sum P_i RR_i} \qquad (3)$$

Where

P_i = the proportion of the population at exposure category 'i', including the unexposed (i.e. $\sum P_i RR_i$ becomes $(P_1 RR_1 + P_2 RR_2 + \ldots\ldots + P_{\text{unexposed}} \times 1)$).

RR_i = the relative risk at exposure category 'i' compared to a reference level.

Since P_i was not known from the study, it was approximated by the proportions of days associated with different pollution concentration groups out of the total days monitored.

- **Calculation of attributable burden (STEP 3)**

Using AF, the expected EBD that can be attributed to a specific ambient air pollutant was calculated as follows.

$$EBD = AF \times \text{Total Burden} \qquad (4)$$

where total burden was calculated as the product of incidence rate of the considered health effect and total population of the study area or total disease burden from hospital records for a specified period (such as a year) of EBD assessment.

2.10 Inclusion criteria and exclusion criteria

Inclusion criteria

- Indoor patients, who were suffering from respiratory health problems.

Exclusion criteria

- Outdoor patients
- Indoor patients who suffered from other health problems than respiratory health problems.

2.11 Data management and analysis

Data were entered and saved in statistical software packages such as Excel and SPSS. Data were coded and recoded wherever necessary for tabulation and analysis. The entered data were checked for consistency and completeness. $PM_{2.5}$ was recorded in 15 minutes intervals at the second and third stations (though sometimes in half hour intervals) and in half hour intervals at the first station. CO and NO_2 concentrations were recorded every minute. Data of monitoring results provided in Excel files were rigorously screened, managed and edited before analysis.
Pollution levels are analyzed and assessed in four dimensions. These are:

- Longitudinal variation (seasonal, monthly and daily variations)
- Between stations variation
- Within 24 hour variation (hourly variation, specific time period variation like morning time, evening time, etc.)
- Comparison of levels between load shedding and normal times by time intervals/stations

Additionally, pollution levels were compared with meteorological variables (temperature, humidity and rainfall). Among the variables, temperature and humidity were measured concurrently with pollution measurements at the installed fixed stations, whereas rainfall data was obtained from the Department of Hydrology and Meteorology, Kathmandu, and are average values of various stations within the valley.

It should be noted that analysis of CO and NO_2 is based upon real CO and NO_2 values (only 1 missing case for real CO) instead of average CO and average NO_2 because of a substantial number of missing cases in average values for both CO and NO_2 (19.5% and 40.5% missing cases for average CO and average NO_2, respectively).

Data for hospitalizations were collected for various respiratory diseases, namely chronic obstructive pulmonary disease (COPD), acute respiratory diseases including upper and lower respiratory infections (tonsillitis, sinusitis, otitis media, common cold and pneumonia, etc.), bronchitis, asthma, respiratory symptoms and other diseases like pleural effusion, tuberculosis, lungs cancer, etc. Mortality was recorded for all-cause deaths. Data on these diseases were collected because of their established associations with ambient air pollution in other parts of the world as well as in Kathmandu Valley (with other pollutants) based upon daily time series data (NHRC 2006).

Table 2: Conversion of units of measurement

Pollutant	Measured unit	Converted unit	Conversion factor	Condition
$PM_{2.5}$	µg/m³	No change	Not required	-
CO	ppm	µg/m³	1ppm = 1145 µg/m³	-
NO_2 (Station 1)	mg/m³	µg/m³	1 mg/m³ = 1000 µg/m³	-
NO2 (Station 2 & 3)	ppm	µg/m³	1 ppm = 1880 µg/m³	at 250C and 1 atmosphere pressure

Source: Urban air quality management tool book, UNEP:
http://ww2.unhabitat.org/wuf/2006/aqm/tool28.htm

Table 3: Nepal's National Ambient Air Quality Standard (NAAQS), 2012

Pollutant	Unit	Averaging Time	Standard
$PM_{2.5}$	µg/m³	24 hour	40
CO	µg/m³	8 hour	10000
NO_2	µg/m³	24 hour	80

2.12 Limitation of the study

This study was limited to within Kathmandu valley of Nepal , thus the study findings may not be generalized for other urban centers of Nepal .

CHAPTER III
FINDINGS

Results are provided in three main sections.

- The first section contains the results of ambient air pollution and weather data analysis.
- The second section contains descriptive analyses of health effect data.
- The third section constitutes statistical models which associate health effects with different covariates including ambient air pollution and weather-related variables.

Summary statistics (mean and SD) of levels of pollution for $PM_{2.5}$, CO and NO_2 are expressed in $\mu g/m^3$.

3.1 Status of ambient air pollution in Kathmandu valley

The status of ambient air pollution is assessed in the following sub-sections.

3.1.1 Assessment of longitudinal variation

Longitudinal variation of pollutants is assessed separately by seasonal, monthly and daily variations as shown below for different parameters in the following sections.

3.1.1.1 Overall scenario of Kathmandu valley (for all three stations): Assessment of seasonal variation

Table 4: Season-months in Nepal

Season	Month
Spring/Pre-monsoon	Falgun-Baishak
Summer/Monsoon	Jestha-Shrawan
Autumn/Post-monsoon	Bhadra-Kartik
Winter	Manshir-Magh

The table above shows the season according to various months in Nepal.

Table 5: $PM_{2.5}$ scenario of Kathmandu valley (for all three stations): Assessment of seasonal variation

Season	Mean	N	SD	CV
Spring/Pre-monsoon	70.0	20513	56.4	80.6
Summer/Monsoon	23.8	22235	28.6	120.1
Autumn/Post-monsoon	23.7	22030	27.1	114.4
Winter	82.0	21116	58.7	71.7
Total	49.1	85894	52.1	106.0

Interpretation / Assessment

$PM_{2.5}$ levels were observed to be high in spring and winter seasons (above 70) and low in monsoon and autumn seasons (below 25). Rainy and hot seasons are characterized by low $PM_{2.5}$ levels whereas dry seasons and relatively cold seasons are characterized by high $PM_{2.5}$ levels. Levels of variation as assessed by coefficient of variance (CV) are high in monsoon season and autumn (115-120) compared to dry seasons (70-80).

Table 6: CO scenario of Kathmandu valley (for all three stations): Assessment of seasonal variation.

Season	Mean	N	SD	CV
Spring	447.3	348518	1541.90	344.7
Summer	502.7	345159	4937.17	982.1
Autumn	298.4	397446	1180.25	395.5
Winter	517.3	380150	1116.11	215.8
Total	438.2	1471273	2643.43	603.3

Interpretation / Assessment

Carbon monoxide levels were observed to be the lowest in Autumn and the levels to be fairly consistent from winter through to summer (above 500). Interestingly, seasonal means are high in dry as well as wet seasons and indicate that temperature and rainfall are not correlated with seasonal means of CO levels. CV is very high year-round, though highest in Summer and lowest in winter.

Table 7: NO_2 scenario of Kathmandu valley (for all three stations): Assessment of seasonal variation

Season	Mean	N	SD	CV
Spring	267.0	374746	1075.1	402.6
Summer	97.3	396223	337.9	347.2
Autumn	47.1	420320	101.0	214.3
Winter	314.7	368603	266.3	84.6
Total	175.9	1559892	582.0	330.9

Interpretation / Assessment

Nitrogen dioxide levels were observed to be high in spring and winter and relatively low in monsoon season and particularly autumn. Similar to the seasonal variation of $PM_{2.5}$, NO_2 shows relatively low levels during hot and wet seasons and high levels during dry seasons, suggesting that meteorological conditions do have significant effects on NO_2 levels. CV is highest in spring and lowest in winter.

3.1.1.2 Monthly variation

The overall scenario of monthly pollution levels considering all the three stations is assessed in the following sub-sections separately for different pollutants.

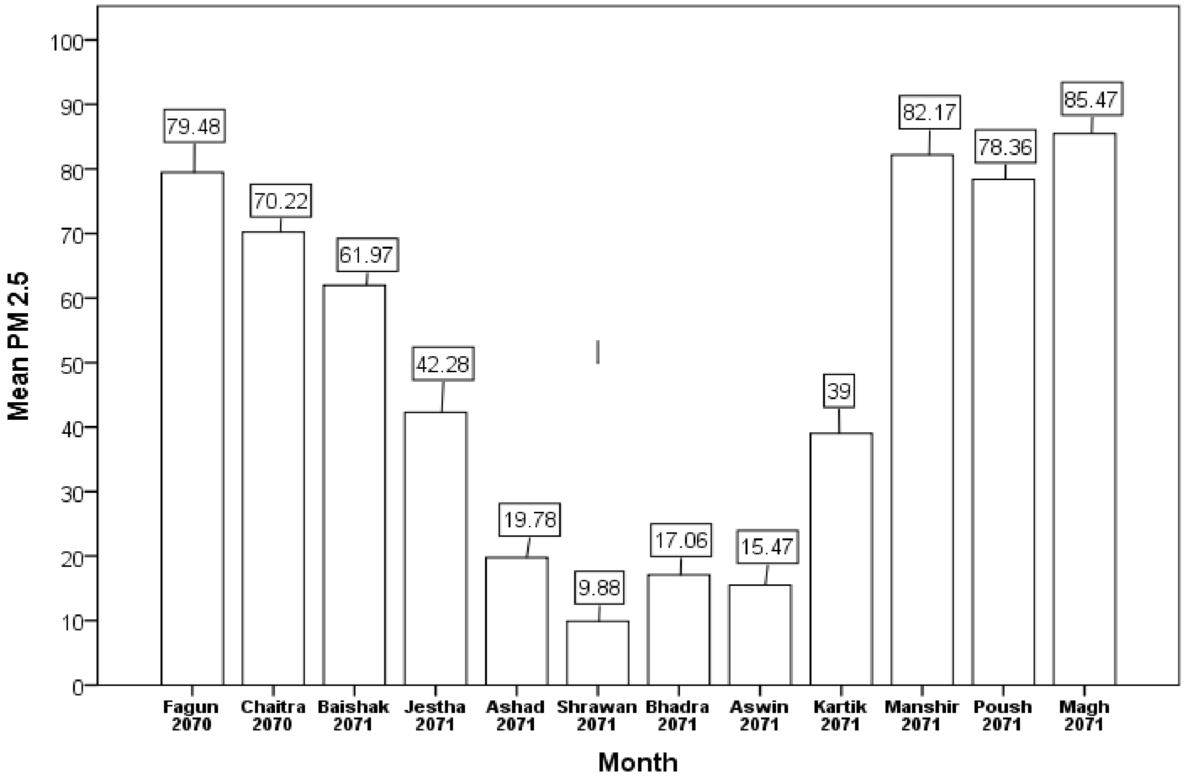


Figure 2: $PM_{2.5}$ scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Interpretation / Assessment

A declining trend of monthly averages was seen from the month of Falgun 2070 to Shrawan 2071. An increasing trend of monthly average was seen from Shrawan 2071 to Manshir 2071, with a slight decrease in Aswin 2071 and Poush 2071. Warmer months with higher rainfall witness relatively less $PM_{2.5}$ pollution in the ambient air of Kathmandu Valley compared to colder months. Monsoon season shows substantially lowered $PM_{2.5}$ average levels (less than 20) compared to other months. Highest daily average fell in the month of Magh and lowest fell in the month of Shrawan. Low $PM_{2.5}$ levels prevailed for four consecutive months from Ashad to Aswin (below 20) and very high levels from Manshir to Baishak (above 60).

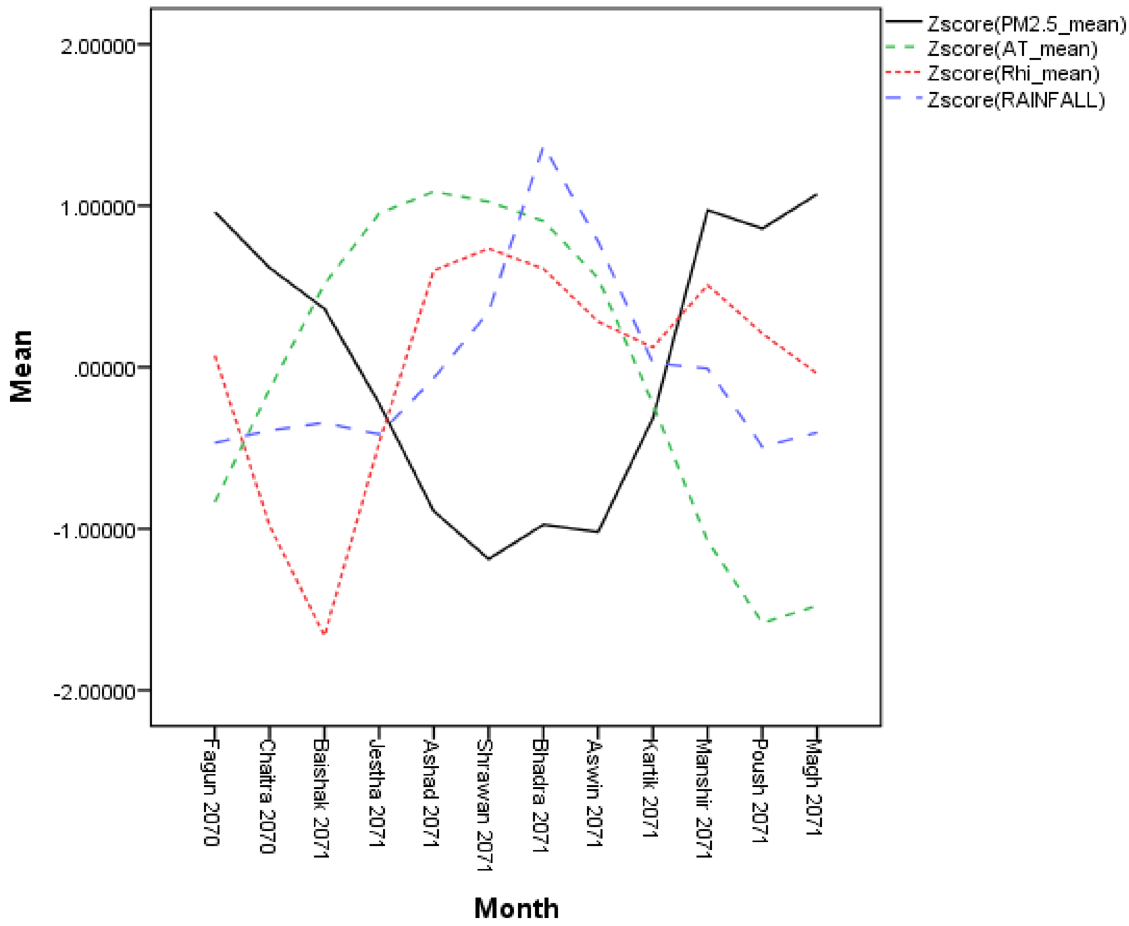


Figure 3: Weather and $PM_{2.5}$ scenario of Kathmandu valley (for all three stations): Assessment of monthly variation by Z standardized score

Table 8 : Statistical correlation of $PM_{2.5}$ with weather

Correlations of monthly averages (N=12)					
		$PM_{2.5}$	**Temperature**	**Humidity**	**Rainfall**
$PM_{2.5}$	Pearson Correlation	1	-.863**	-.404	-.724**
	Sig. (2-tailed)		.000	.192	.008
Temperature	Pearson Correlation	-.863**	1	.009	.498
	Sig. (2-tailed)	.000		.977	.100
Humidity	Pearson Correlation	-.404	.009	1	.513
	Sig. (2-tailed)	.192	.977		.088
Rainfall	Pearson Correlation	-.724**	.498	.513	1
	Sig. (2-tailed)	.008	.100	.088	
** Correlation is significant at the 0.01 level (2-tailed).					

Interpretation / Assessment

The multiple line graph depicting Z (standardized) scores demonstrates negative associations between $PM_{2.5}$ and the meteorological variables. This means that a low level of $PM_{2.5}$ is associated with high temperature, humidity and rainfall, and vice versa. Standardization was used since units of measurement differ between variables. The correlation matrix shows statistically significant negative correlations between PM level and weather parameters except for humidity.

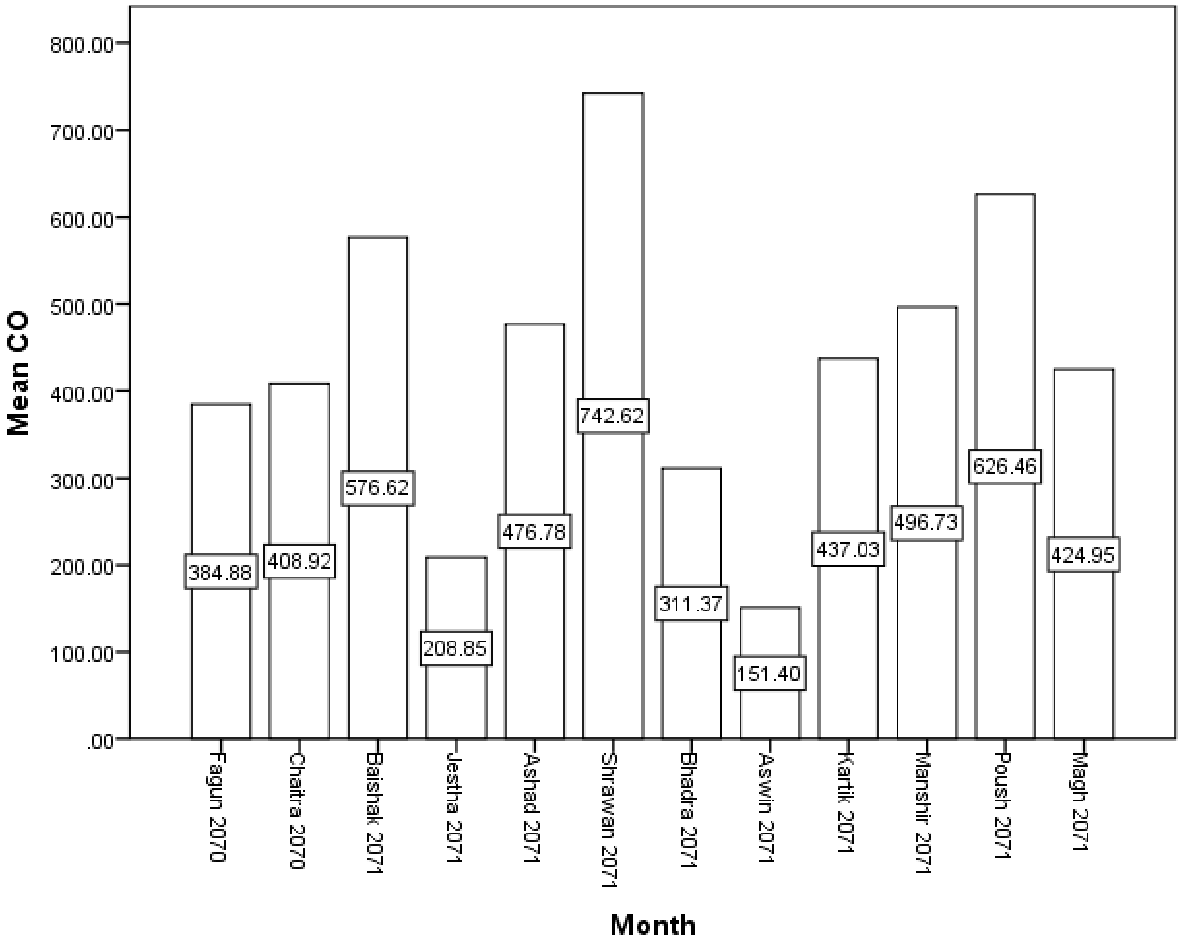


Figure 4: CO scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Interpretation / Assessment

There is a cyclic variation in monthly average of CO. Monthly CO average rises from Falgun 2070 till Baishak 2071, decreases in Jestha 2071 and again increases till the month of Shrawan 2071, decreases till Aswin, increases till Poush 2071, and then decreases in Magh 2071. Monthly CO average is the highest in Shrawan and the lowest in Aswin.

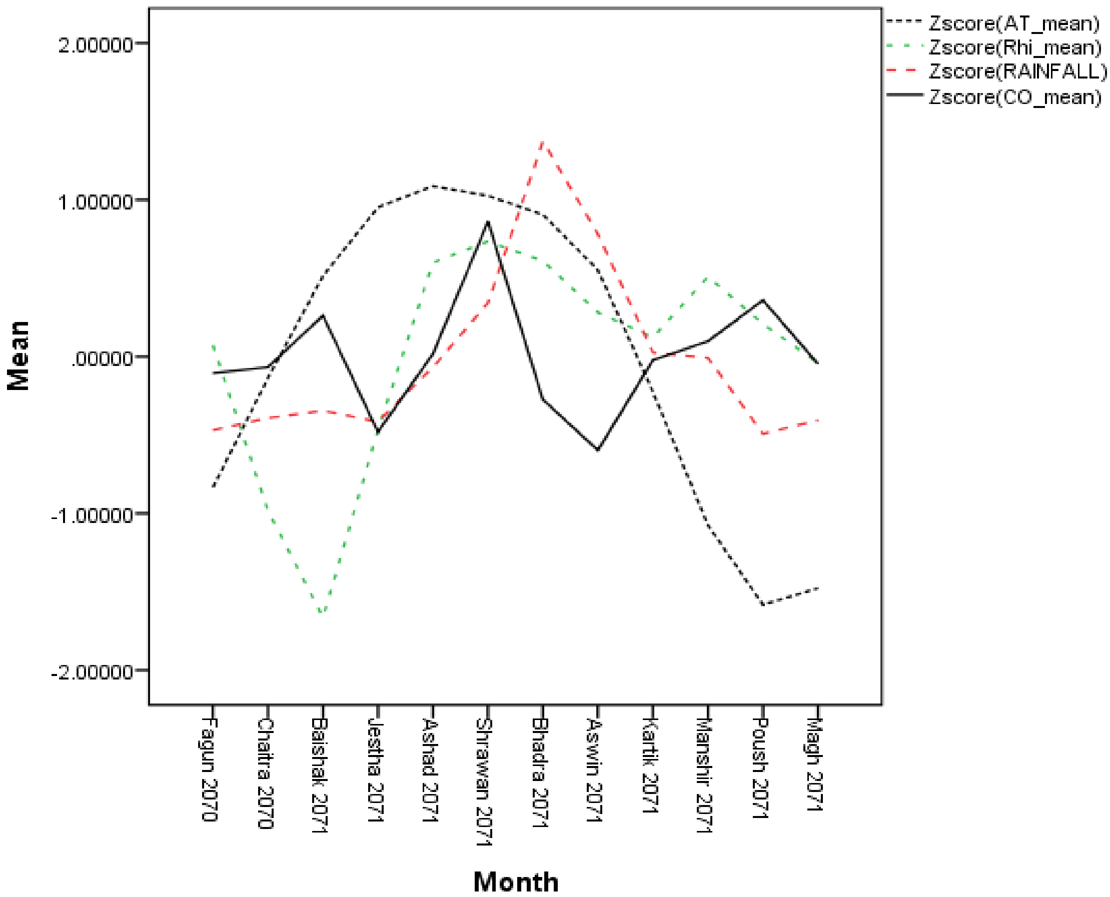


Figure 5: Weather and CO scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Table 9: Statistical correlation of CO with weather situation

Correlations (using monthly averages); N=12					
		CO	**Temperature**	**Humidity**	**Rainfall**
CO	Correlation	1	-.197	.053	-.282
	Sig. (2-tailed)		.539	.870	.375
Temperature	Correlation	-.197	1	.009	.498
	Sig. (2-tailed)	.539		.977	.100
Humidity	Correlation	.053	.009	1	.513
	Sig. (2-tailed)	.870	.977		.088
Rainfall	Correlation	-.282	.498	.513	1
	Sig. (2-tailed)	.375	.100	.088	

Interpretation / Assessment

The multiple line graphs do not show any clear pattern regarding associations between CO and meteorological parameters as was seen in case of $PM_{2.5.}$ The correlation matrix also shows that there was no statistically significant association between CO and meteorological parameters.

Table 10: NO_2 scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Month	Mean	N	SD	CV
Falgun 2070	348.2	118917	1196.7	343.7
Chaitra 2070	98.4	125061	392.5	398.9
Baishak 2071	354.5	130768	1349.8	380.8
Jestha 2071	148.5	130468	268.7	181.0
Ashad 2071	110.8	135527	459.4	414.7
Shrawan 2071	32.0	130228	219.6	685.9
Bhadra 2071	13.8	126570	35.0	253.4
Aswin 2071	49.0	126967	107.9	220.2
Kartik 2071	71.0	166783	120.4	169.6
Manshir 2071	212.1	125280	147.3	69.4
Poush 2071	221.4	126681	211.4	95.5
Magh 2071	526.1	116642	294.8	56.0
Total	175.9	1559892	582.0	330.9

Interpretation / Assessment

Monthly NO_2 levels are low from Shrawan to Kartik (below 80), very high in Magh, Falgun and Baishak (above 300), and high in the remaining months (above 90). On average, winter and dry months (particularly Magh) have higher NO_2 levels compared to summer and wet months. Variation is, relatively speaking, low only in winter months (Manshir-Magh) and is high or very high in the rest of the months.

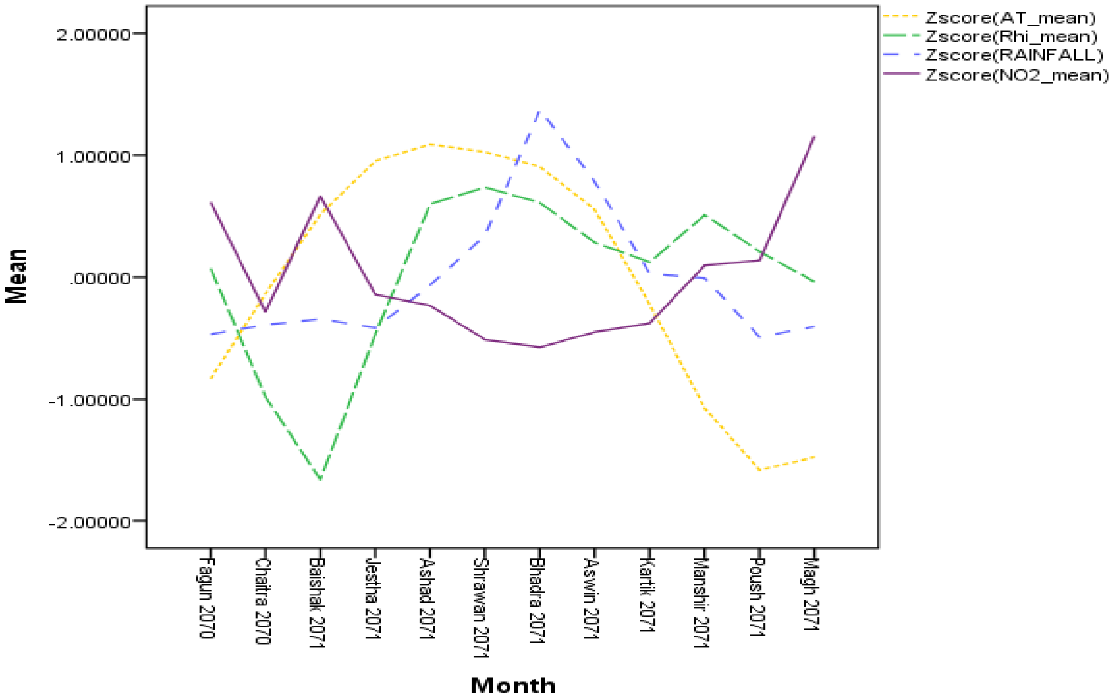


Figure 6: Weather and NO_2 scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Table 11: Statistical correlation of NO_2 with weather situation

Correlations (using monthly data); N=12					
		NO_2	**Temperature**	**Humidity**	**Rainfall**
NO_2	Correlation	1	-.634*	-.388	-.633*
	Sig. (2-tailed)		.027	.212	.027
Temperature	Correlation	-.634*	1	.009	.498
	Sig. (2-tailed)	.027		.977	.100
Humidity	Correlation	-.388	.009	1	.513
	Sig. (2-tailed)	.212	.977		.088
Rainfall	Correlation	-.633*	.498	.513	1
	Sig. (2-tailed)	.027	.100	.088	
*. Correlation is significant at the 0.05 level (2-tailed).					

Interpretation /Assessment

High temperature, humidity and rainfall are correlated with low NO_2 levels as seen in the graph above. The negative association between NO_2 level and meteorological parameters is statistically significant for rainfall and temperature, as shown in the correlation matrix.

3.1.1.3 Between stations monthly variation

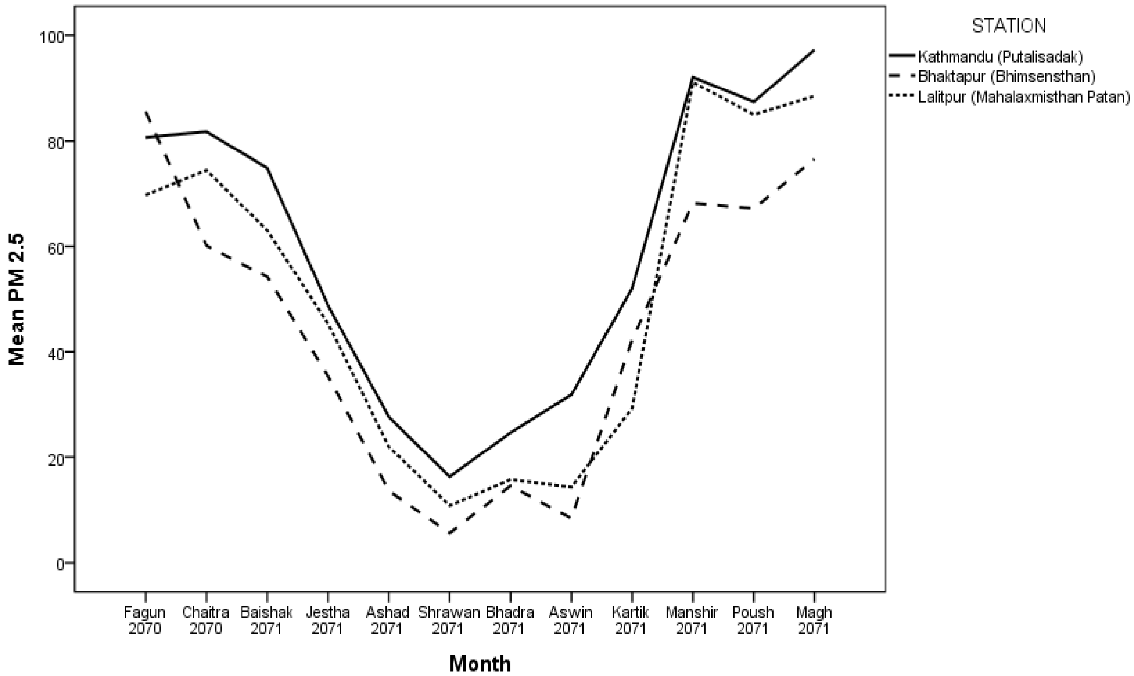


Figure 7: $PM_{2.5}$ scenario of Kathmandu valley (for all three stations): Between stations monthly variation

Interpretation /Assessment

The line graphs for Kathmandu and Bhaktapur stations show a decreasing trend of monthly $PM_{2.5}$ levels from the dry season to the rainy season, and reach the lowest values in Shrawan, For Lalitpur station, $PM_{2.5}$ level rises from Falgun to a maximum in Chaitra and then decreases in line with the other two stations. Among stations, Bhaktapur shows the lowest ambient $PM_{2.5}$ levels from Chaitra (60) onwards, and the level is highest in Falgun (85.5). Lalitpur station experiences monthly values of $PM_{2.5}$ in between the other two stations from Chaitra onwards and is at lowest level in Falgun (79.5). Kathmandu station observes the highest $PM_{2.5}$ levels of the three stations in all months except for Falgun, when the monthly average is slightly lower than that of Bhaktapur station (80.7).

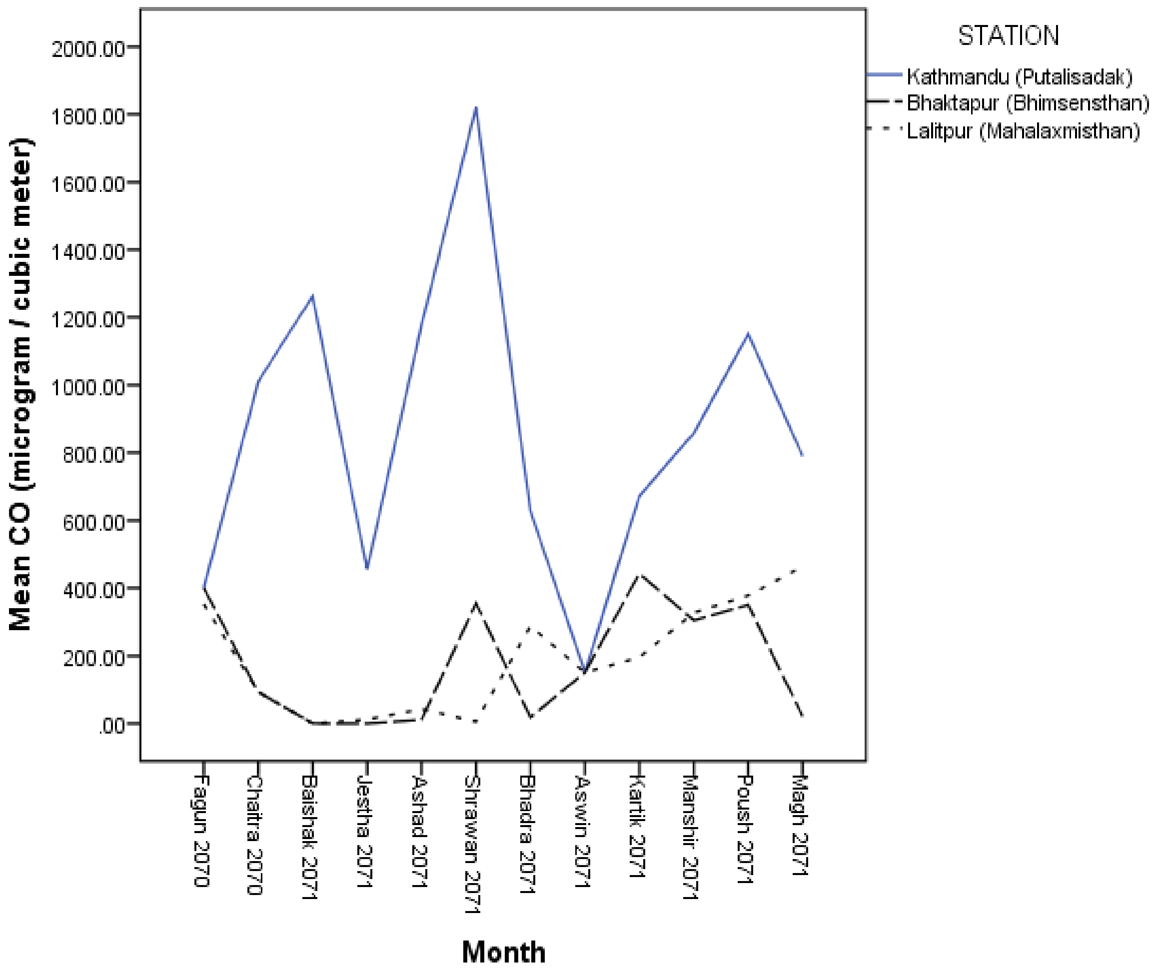


Figure 8: CO scenario of Kathmandu valley (for all three stations): Between stations monthly variation

Interpretation / Assessment

Comparatively, CO levels are much higher in Kathmandu station than the other two district stations during all months except Falgun and Aswin, which could be due to the higher traffic density in Kathmandu compared to Lalitpur and Bhaktapur. High values of CO are observed in Chaitra, Baishak, Ashad, Shrawan and Poush in Kathmandu, which include hot as well as cold months. In Bhaktapur station, CO levels are low during Baishak-Ashad, Bhadra and Magh, which include hot as well as cold months. In Lalitpur station, CO levels are low during Baishak-Shrawan only, and relatively higher in rest of the months.

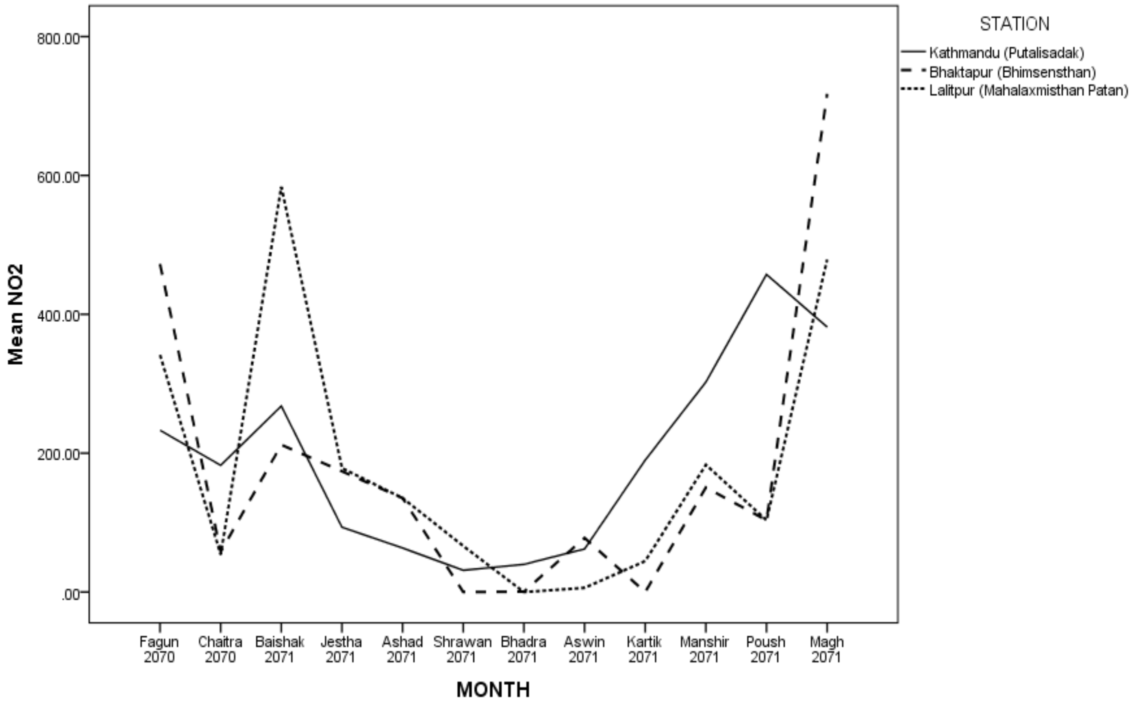


Figure 9: NO_2 scenario of Kathmandu valley (for all three stations): Between stations monthly variation

Interpretation / Assessment

In contrast to CO levels, NO_2 levels are not notably higher at Kathmandu station for the majority of months. Levels are higher only in Kartik-Poush, Chaitra and Bhadra, which indicates that NO_2 may not be largely mediated by traffic only. Low levels of NO_2 are seen for all three stations only during Shrawan and Bhadra, whereas high levels are seen in Magh and Baishak for all three stations. Otherwise, low levels and high levels are not consistently distributed between stations.

3.1.1.4 Overall scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

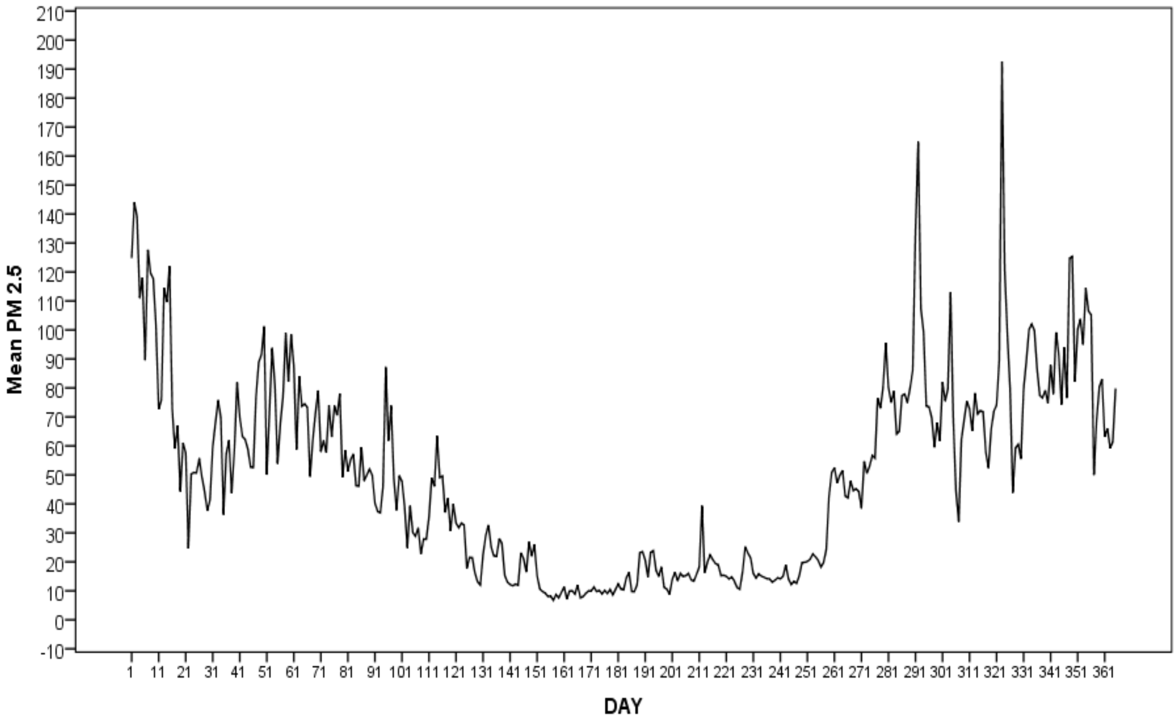


Figure 10: $PM_{2.5}$ scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

Sharp decline in daily ambient average in Falgun, increases steadily in Chaitra then decreases gradually for the next four months, and reaches the lowest level during the month of Shrawan (around 10-20). Most of the daily averages are above the Nepal' NAAQS of 40µg/m^3 in the months from Falgun to Jestha. From Ashad to Aswin the averages are below the standard. Thereafter the averages gradually rise again, reaching the highest levels in the winter months. There are some very high spikes during winter when levels rise very sharply (170-200µg/m^3), which is around 4-5 times higher than the NAAQS standard.

Table 12: Statistical correlation of $PM_{2.5}$ with weather situation (for all the three stations): Assessment of daily variation

Correlations with daily averages (N=365)					
		$PM_{2.5}$	Temperature	Humidity	Rainfall
$PM_{2.5}$	Correlation	1	-.711**	-.207**	-.345**
	Sig. (2-tailed)		.000	.000	.000
Temperature	Correlation	-.711**	1	-.091	.250**
	Sig. (2-tailed)	.000		.082	.000
Humidity	Correlation	-.207**	-.091	1	.209**
	Sig. (2-tailed)	.000	.082		.000
Rainfall	Correlation	-.345**	.250**	.209**	1
	Sig. (2-tailed)	.000	.000	.000	
**. Correlation is significant at the 0.01 level (2-tailed).					

Highly statistically significant negative correlations between daily $PM_{2.5}$ average and meteorological parameters are indicated.

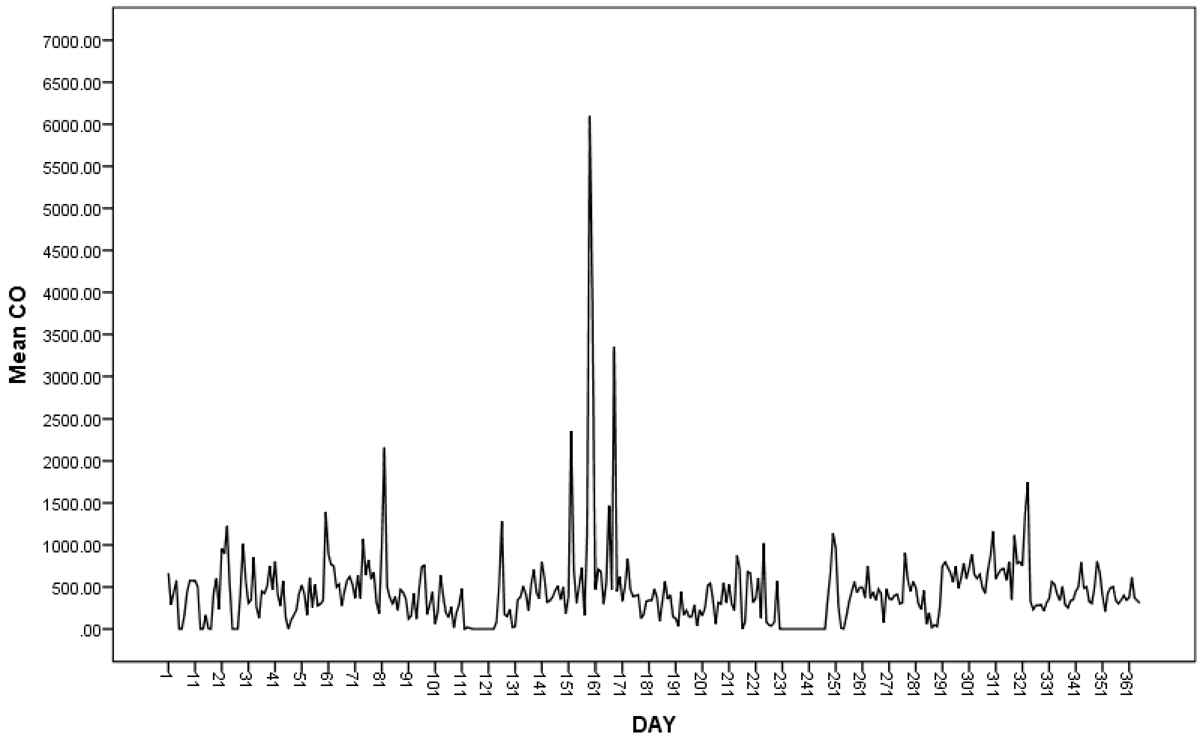


Figure 11: CO scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

Very high spikes in CO averages are seen on days 259, 160 and 168 (above 3000). Around 15 days recorded daily averages above 1000. This included warm as well as cold days, giving no indication of a significant effect of meteorological effects on CO levels. All daily CO averages levels are below the 8 hour standard (10000), indicating that CO levels are not dangerously high in Kathmandu Valley's ambient air.

Table 13: Statistical correlation of CO with weather situation (for all the three stations): Assessment of daily variation

Correlations with daily averages (N=365)					
		CO	Temperature	Humidity	Rainfall
CO	Correlation	1	-.069	.063	-.081
	Sig. (2-tailed)		.190	.231	.124
Temperature	Correlation	-.069	1	-.091	.250**
	Sig. (2-tailed)	.190		.082	.000
RH mean	Correlation	.063	-.091	1	.209**
	Sig. (2-tailed)	.231	.082		.000
Rainfall	Correlation	-.081	.250**	.209**	1
	Sig. (2-tailed)	.124	.000	.000	
**. Correlation is significant at the 0.01 level (2-tailed).					

There is no significant correlation between CO and any meteorological parameters when considering daily averages. This reveals that changes in CO levels in ambient air in Kathmandu Valley are not governed by changes in meteorological conditions.

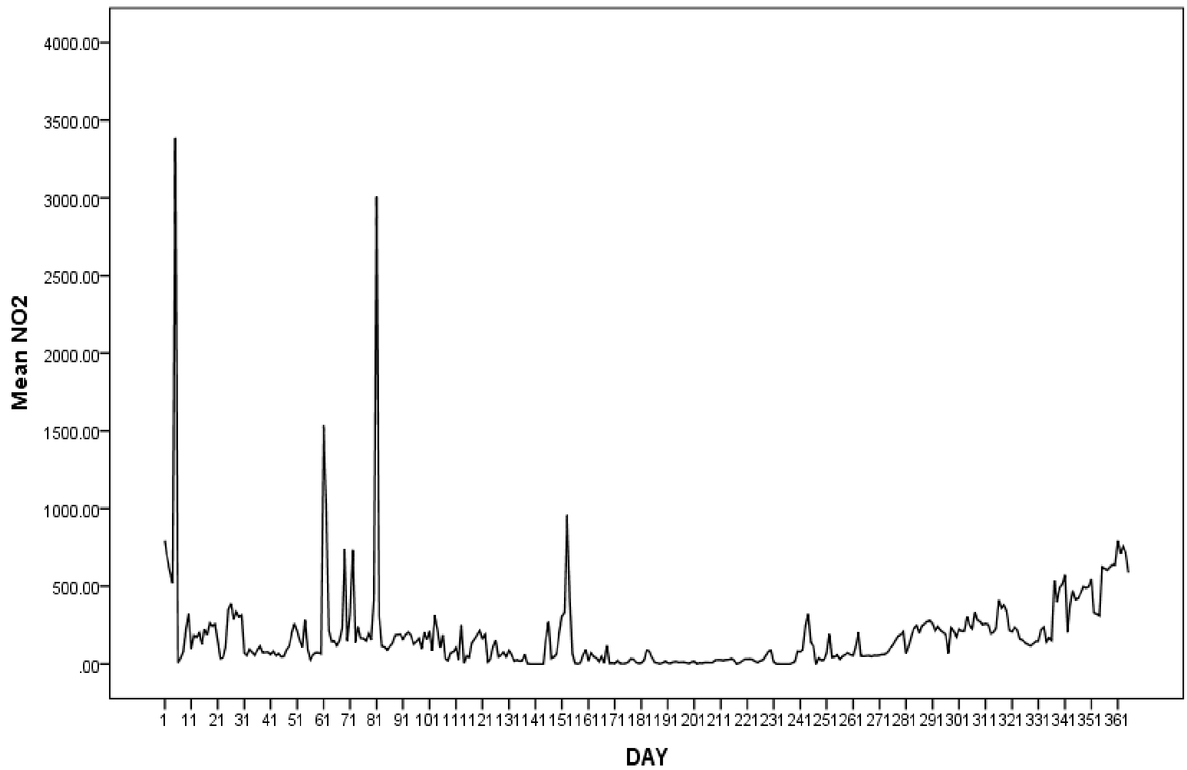


Figure 12: NO_2 scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

Unusually high spikes of daily NO_2 averages are seen on several occasions in the initial few months of monitoring. In the first five months of monitoring, barring unusual high spikes, no definite increasing or decreasing trends are noticed. In the sixth and seventh months (Bhadra and Aswin), daily averages are more stable and comparatively low. Thereafter, the average steadily increases with small fluctuations throughout the winter months as well as Poush and Magh, and daily levels are relatively higher than Summer months. Daily averages are higher in the majority of days than the NAAQS 24-hour standard of 80, which signifies that ambient air of Kathmandu Valley is polluted with harmful levels of NO_2, with occasional very high spikes (more than 1000 - more than 12 times higher than the standard). The main sources of NO_2 are vehicular and industrial emissions. The current scenario poses serious health concerns for people living in the valley.

Table 14: Statistical correlation of NO_2 with weather situation (for all the three stations): Assessment of daily variation

Correlations (daily means), N=365					
		Temperature	**Humidity**	**Rainfall**	**NO_2**
Temperature	Correlation	1	-.091	.250**	-.350**
	Sig. (2-tailed)		.082	.000	.000
Humidity	Correlation	-.091	1	.209**	-.072
	Sig. (2-tailed)	.082		.000	.169
Rainfall	Correlation	.250**	.209**	1	-.117*
	Sig. (2-tailed)	.000	.000		.025
NO_2	Correlation	-.350**	-.072	-.117*	1
	Sig. (2-tailed)	.000	.169	.025	
** Correlation is significant at the 0.01 level (2-tailed).					
* Correlation is significant at the 0.05 level (2-tailed).					

On a daily average basis, statistically significant negative correlations exist between NO_2 with temperature and rainfall.

3.1.1.5 Comparison with NAAQS standard

Frequency distribution of number of days with daily averages above versus below the Nepal's NAAQS standard 2012.

Table 15: $PM_{2.5}$ (24-hour average) comparison with NAAQS standard

			Standard		Total
			Outside NAAQS	Within NAAQS	
Month	Falgun 2070	Number	28	2	30
		% within Month	93.3%	6.7%	100.0%
	Chaitra 2070	Number	29	1	30
		% within Month	96.7%	3.3%	100.0%
	Baishak 2071	Number	31	0	31
		% within Month	100.0%	0.0%	100.0%
	Jestha 2071	Number	14	17	31
		% within Month	45.2%	54.8%	100.0%
	Ashad 2071	Number	0	32	32
		% within Month	0.0%	100.0%	100.0%
	Shrawan 2071	Number	0	31	31
		% within Month	0.0%	100.0%	100.0%
	Bhadra 2071	Number	0	31	31
		% within Month	0.0%	100.0%	100.0%
	Aswin 2071	Number	0	31	31
		% within Month	0.0%	100.0%	100.0%
	Kartik 2071	Number	18	12	30
		% within Month	60.0%	40.0%	100.0%
	Manshir 2071	Number	29	0	29
		% within Month	100.0%	0.0%	100.0%
	Poush 2071	Number	29	1	30
		% within Month	96.7%	3.3%	100.0%
	Magh 2071	Number	29	0	29
		% within Month	100.0%	0.0%	100.0%
Total		Number	207	158	365
		% within Month	56.7%	43.3%	100.0%

Interpretation /Assessment

From Falgun to Baishak (91 days), only three days were recorded with daily averages below the NAAQS standard. In Jestha, 17 days (54.8%) had averages below the standard. From Ashad to Aswin, the scenario is completely different, and all averages are below the standard. In Kartik 18 days (60%) were recorded with averages above the standard. In Manshir-Magh only one day was recorded with a daily average below the standard.

CO (8-hour average) comparison with NAAQS standard

Since the ambient air quality standard of NO_2 is usually expressed in 8-hour averages, daily 8-hour averages for the whole monitoring period is also graphed as follows.

Daily midnight-morning (till 8 am) averages of CO

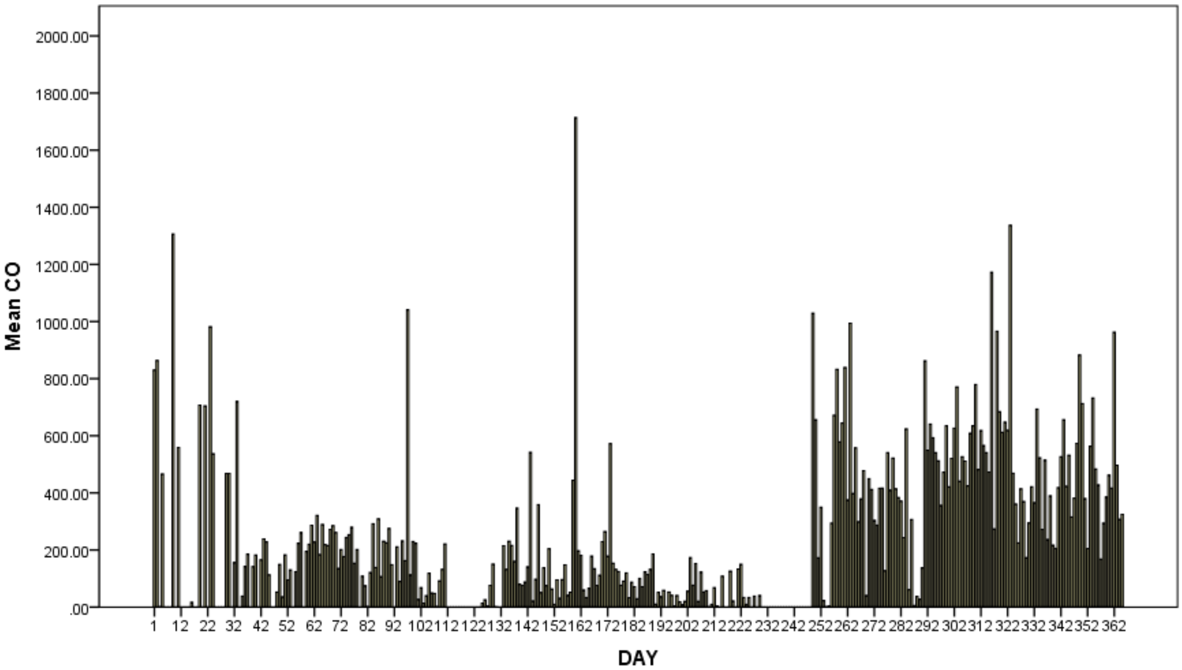


Figure 13: CO (8-Hour average) comparison with NAAQS standard

The averages are well below the NAAQS (10000 µg/m^3) standard.

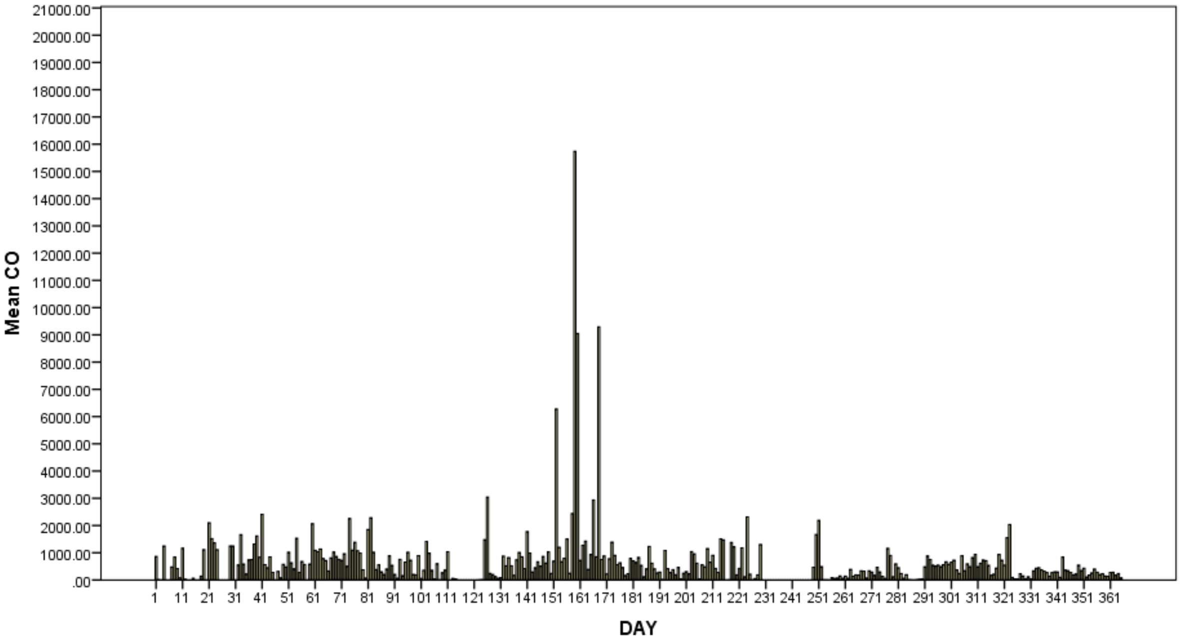


Figure 14: Daily morning-afternoon (8 am-4 pm) averages of CO

Only a single day recorded a CO level above the standard during an 8-hour period.

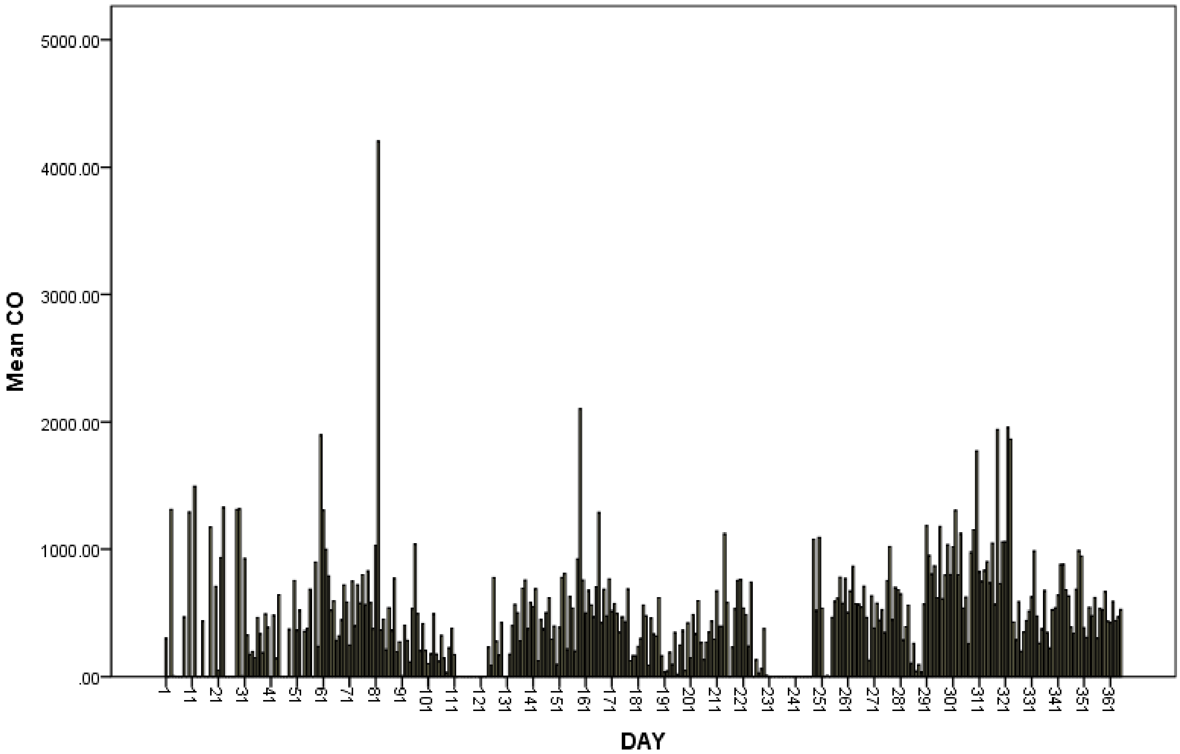


Figure 15: Afternoon-midnight averages of CO

The averages are well below the NAAQS (10000 µg/m^3) standard.

Table 16: NO_2 scenario of Kathmandu Valley (for all the three stations): Assessment of 24-hour average

Note: NAAQS 24-hour average is 80µg/m

			Standard		Total
			Within standard	Above standard	
Month	Falgun 2070	Number	5	25	30
		% within Month	16.7%	83.3%	100.0%
	Chaitra 2070	Number	17	13	30
		% within Month	56.7%	43.3%	100.0%
	Baishak 2071	Number	0	31	31
		% within Month	0.0%	100.0%	100.0%
	Jestha 2071	Number	8	23	31
		% within Month	25.8%	74.2%	100.0%
	Ashad 2071	Number	22	10	32
		% within Month	68.8%	31.3%	100.0%
	Shrawan 2071	Number	27	4	31
		% within Month	87.1%	12.9%	100.0%
	Bhadra 2071	Number	31	0	31
		% within Month	100.0%	0.0%	100.0%
	Aswin 2071	Number	23	8	31
		% within Month	74.2%	25.8%	100.0%
	Kartik 2071	Number	24	6	30
		% within Month	80.0%	20.0%	100.0%
	Manshir 2071	Number	2	27	29
		% within Month	6.9%	93.1%	100.0%
	Poush 2071	Number	0	30	30
		% within Month	0.0%	100.0%	100.0%
	Magh 2071	Number	0	29	29
		% within Month	0.0%	100.0%	100.0%
Total		Number	159	206	365
		% within Month	43.6%	56.4%	100.0%

Interpretation/Assessment

All daily averages were within the standard only in Bhadra. In Chaitra, Ashad, Shrawan, Aswin and Kartik, the majority of days recorded averages below the standard. In Baishak, Poush and Magh all averages were above the standard. In Falgun, Jestha, and Manshir very few days recorded averages below the standard. Winter months (Manshir-Magh) are found to be most highly polluted with ambient NO_2 levels. Only two days were within the standard. Overall, a majority of days (56.4%) passed with ambient NO_2 above the Nepal standard, signifying that Kathmandu Valley's ambient air is often polluted with harmful levels of NO_2.

3.1.1.6 Between stations daily variation

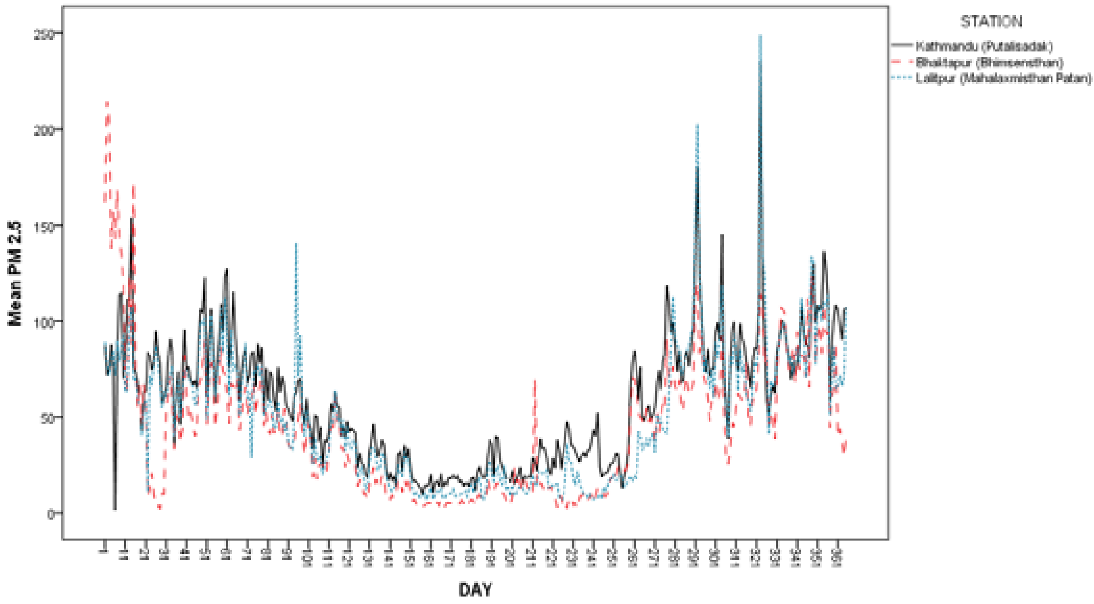


Figure 16: $PM_{2.5}$ scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

The red line represents Bhaktapur daily averages, the blue line represents Lalitpur averages and the black line represents Kathmandu averages. For the black line (Kathmandu) most days are above the other two lines, whereas the red line (Bhaktapur) is usually the lowest of the three. To begin with the red line (Bhaktapur) is the highest, in the month of Falgun. High spikes are seen for at all stations at different times.

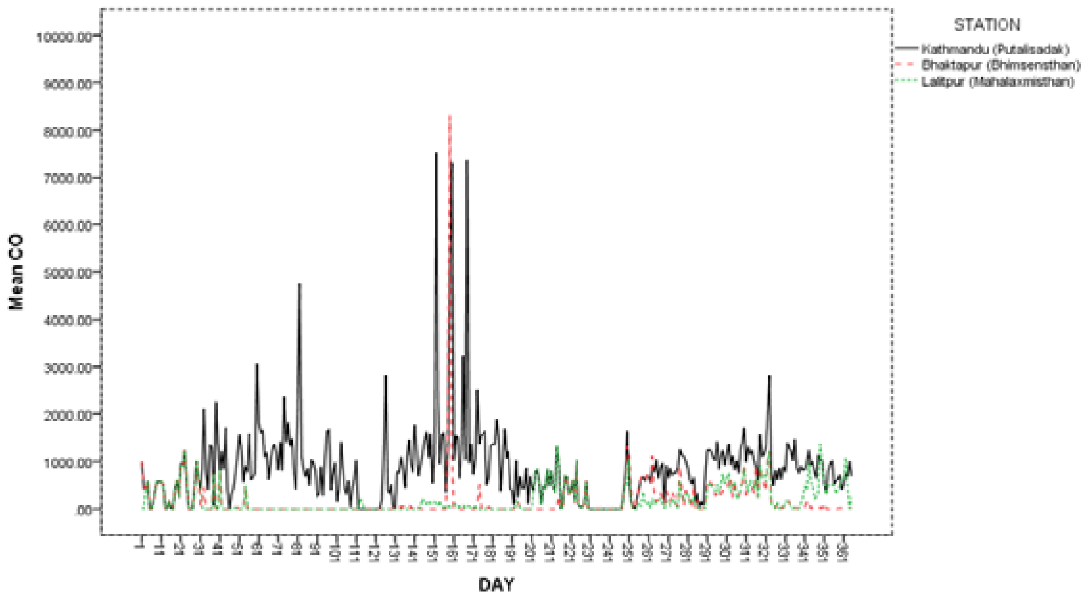


Figure 17: CO scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

The black line representing Kathmandu station CO average is seen to reach substantially higher levels in the majority of days. This line completely overlaps the red line (Bhaktapur) in many days too, which implies that Kathmandu CO levels coincide with Bhaktapur levels on many occasions. In winter months, Lalitpur averages (green line) as well as the red line are below the black line, signifying that Kathmandu is relatively more polluted in those months. The green line is at lowest levels most days, demonstrating that Lalitpur is relatively less polluted with CO. Encouragingly, even the high spikes are below the NAAQS standard of 10000.

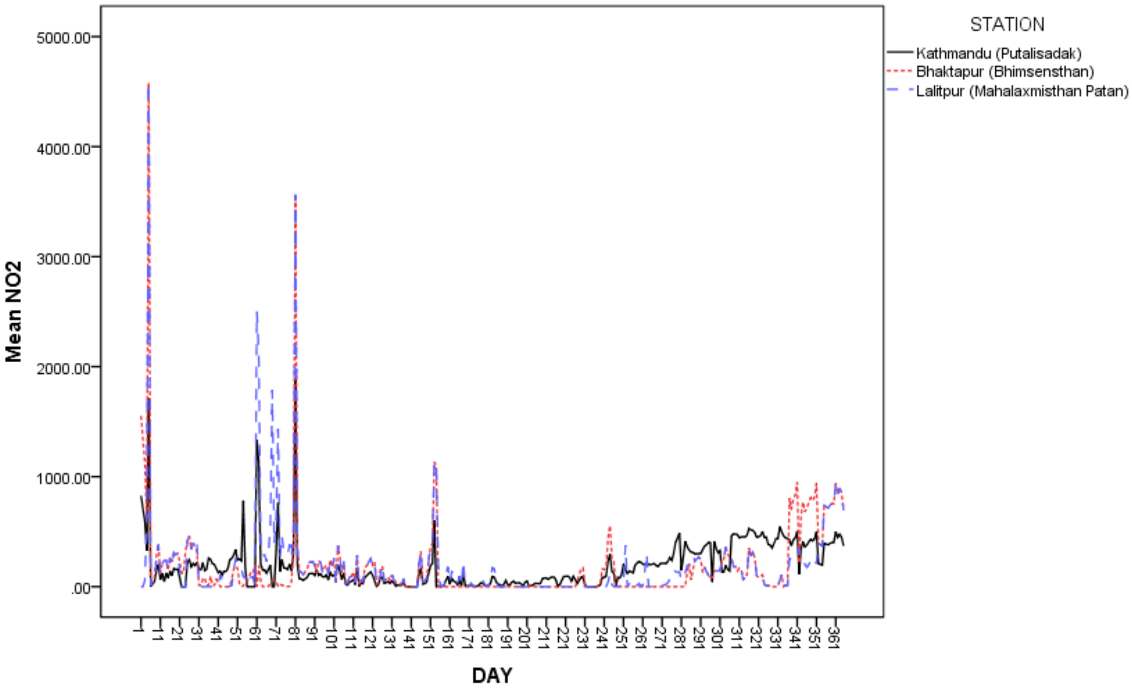


Figure 18: NO_2 scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Interpretation / Assessment

In contrast to $PM_{2.5}$ and CO pollution at the Kathmandu station, which showed high levels in the majority of days compared to the other stations, the same is not true of NO_2 pollution. In this case, there are many days where Kathmandu's daily averages were exceeded either by the red line (Bhaktapur) or blue line (Lalitpur). This implies that NO_2 pollution in the ambient air may not be largely attributable to vehicular emissions alone. In fact, high spikes are seen for the Bhaktapur and Lalitpur stations too.

3.1.2 Assessment of within 24 hr variation

3.1.2.1 Assessment in 3 hours intervals for all stations

Table 17: $PM_{2.5}$ assessment in 3 hours intervals for all stations

Period	Mean	N	SD	CV
After Midnight (0-3 AM)	36.2	10770	33.0	91.1
Before Dawn (3-6 AM)	40.8	10746	35.5	87.1
Morning (6-9 AM)	74.0	10716	63.4	85.7
Before Noon (9-12 Noon)	66.2	10736	66.9	100.9
Afternoon (12-3 PM)	34.7	10730	38.7	111.4
Late Afternoon (3-6 PM)	36.5	10694	42.9	117.7
Evening (6-9 PM)	55.7	10737	54.0	97.0
Night (9-12 Midnight)	48.8	10765	55.1	112.8
Total	49.1	85894	52.1	106.0

Interpretation / Assessment

A cyclical 24 hour pattern of low and high values (averages) of $PM_{2.5}$ is observed when considering three hour intervals. Pollution is at a minimum level during the 3 hour interval after midnight (36.2 $\mu g/m^3$) and increases slightly to 40.7$\mu g/m^3$ during the before-dawn period. Thereafter it increases substantially and reaches a peak average (74.0$\mu g/m^3$) during morning. The level then decreases gradually and attains the lowest value (34.7$\mu g/m^3$) during the afternoon period. Finally the level increases until the evening period (55.7$\mu g/m^3$) and again decreases at night (48.8$\mu g/m^3$). Evidently, in the morning period ambient $PM_{2.5}$ level is much higher than at evening.

Table 18: CO assessment in 3 hours intervals for all stations

Three hourly interval	Mean	N	SD	CV
After Midnight (0-3 AM)	167.4	183299	656	391.8
Before Dawn (3-6 AM)	153.4	182804	588.2	383.3
Morning (6-9 AM)	517.4	182838	1058.7	204.6
Before Noon (9-12 Noon)	589.4	182816	1812.2	307.5
Afternoon (12-3 PM)	673.4	183032	6524.3	968.9
Late Afternoon (3-6 PM)	433.2	184056	2355.2	543.7
Evening (6-9 PM)	647.7	184521	1269.6	196
Night (9-12 Midnight)	326.9	184368	946.2	289.5
Total	438.7	1467734	2646	603.2

Interpretation / Assessment

CO levels are found low (150-170) before dawn and increase throughout the morning, reaching maximum (675) during the afternoon. Thereafter, the level dips to around 430 during the late afternoon before increasing again substantially during the evening (648), then decreasing at night (327). The CO average starts to increase from morning through till afternoon, corresponding to the period during which traffic density increases. Furthermore, CO levels increase during the evening, which may be due to increase in traffic density as workers, employees, etc. return home.

Table 19: NO_2 assessment in 3 hour intervals for all stations

Period	Mean	N	SD	CV
After Midnight (0-3 AM)	166.8	180355	285.8	171.4
Before Dawn (3-6 AM)	167.4	148878	236.8	141.4
Morning (6-9 AM)	247.4	140638	485.3	196.2
Before Noon (9-12 Noon)	221.9	159458	987.4	445.0
Afternoon (12-3 PM)	173.1	200401	810.7	468.3
Late Afternoon (3-6 PM)	149.0	235291	670.5	450.1
Evening (6-9 PM)	180.6	243222	495.6	274.4
Night (9-12 Midnight)	152.3	222408	275.5	180.9
Total	178.2	1530651	586.8	329.4

Interpretation / Assessment

NO_2 levels are relatively low (160-170) before dawn and increase substantially in the morning (up to 247). Levels then gradually decrease until they reach lowest point (149) during the late afternoon. Thereafter, levels increase again to around 181 during the evening before decreasing somewhat during the night (152), demonstrating a 24-hour period of cyclic variation. As is the case with $PM_{2.5}$, NO_2 levels in the ambient air of Kathmandu Valley are the highest during the morning period, which is not good for morning walk goers in the valley.

3.1.2.2 Assessment of 3 hour intervals between stations

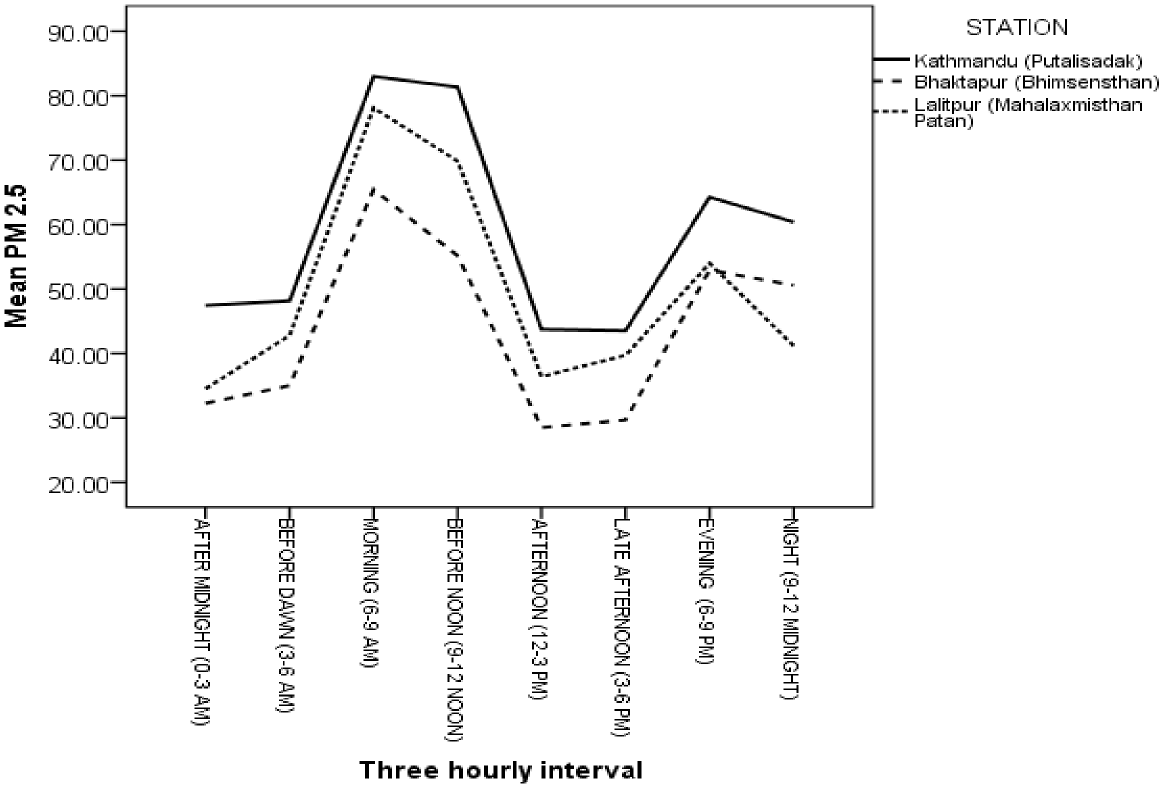


Figure 19: $PM_{2.5}$ assessment of 3 hour intervals between stations

Interpretation / Assessment

If we consider three-hourly interval variation between stations, we observe more or less similar cyclical patterns of rises and falls in $PM_{2.5}$ levels as observed for all three stations combined. The Putalisadak station shows $PM_{2.5}$ averages above the other two, which demonstrate that $PM_{2.5}$ pollution is the highest in Kathmandu. Bhaktapur station shows the lowest $PM_{2.5}$ averages for all three-hourly intervals, and Patan station shows averages in between the other two stations. For all three stations, morning levels show the highest averages throughout the 24 hour period, a rather discouraging finding for morning walkers in Kathmandu Valley.

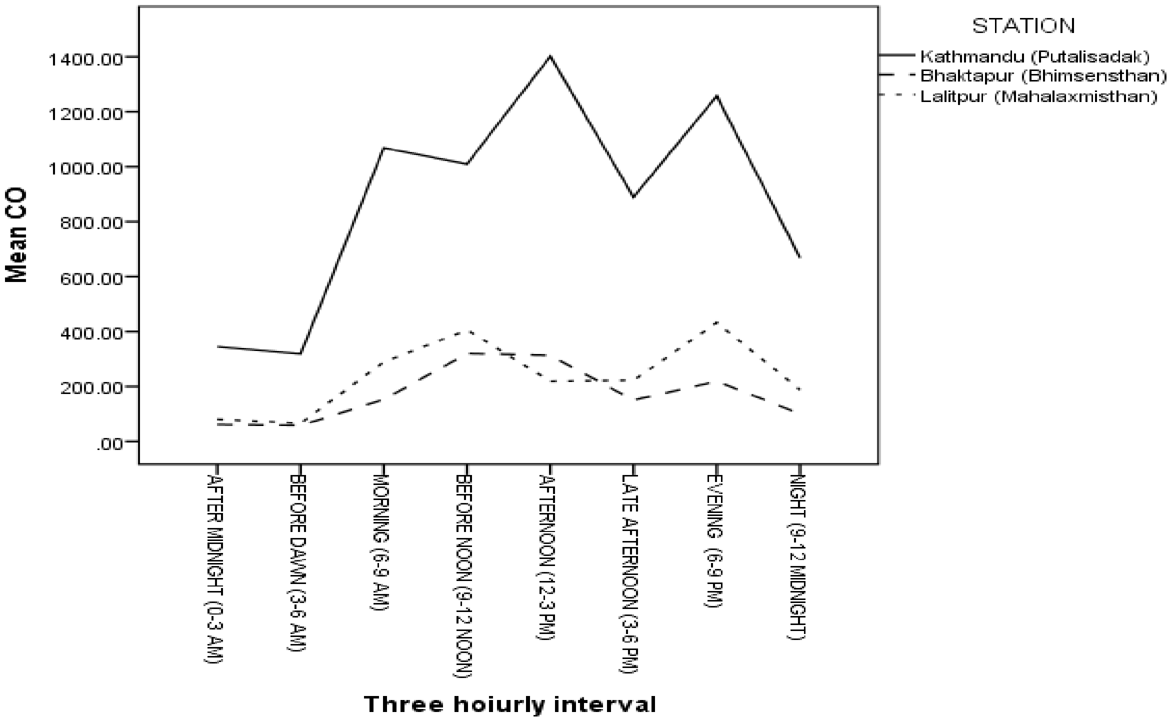


Figure 20: CO assessment of 3 hour intervals between stations

Interpretation / Assessment

For all three-hourly intervals, CO levels are much higher at Kathmandu station than the other two stations. In this station, very high levels (above 1000) were recorded from morning through to afternoon and also in the evening. The Patan and Bhaktapur stations experience similar levels of CO. In both stations, averages are high before noon (300-400) and also in the evening (200-430).

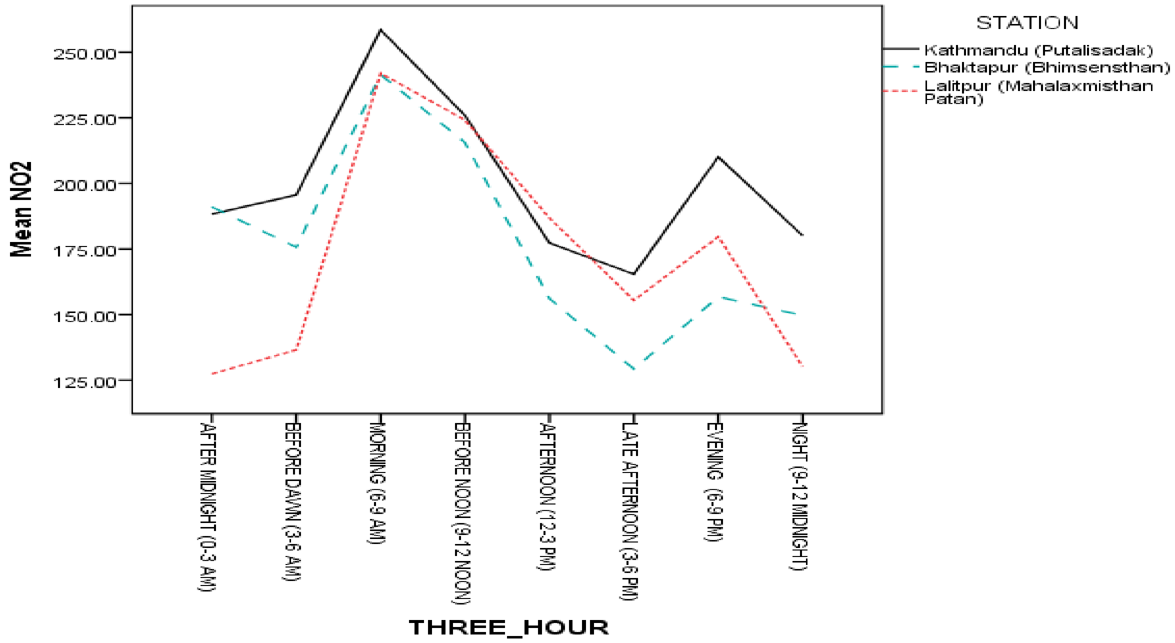


Figure 21: NO_2 assessment of 3 hour intervals between stations

Interpretation / Assessment

Average levels are the highest at Kathmandu station at all times except early afternoon and after midnight. During the period after midnight, Bhaktapur station recorded the highest levels whereas the highest levels during the afternoon period were recorded at Lalitpur station. At all three stations, the morning period showed the highest levels of NO_2 (above 240), which again raises health concerns for morning walkers.

3.1.2.3 Assessment of hourly intervals for all stations

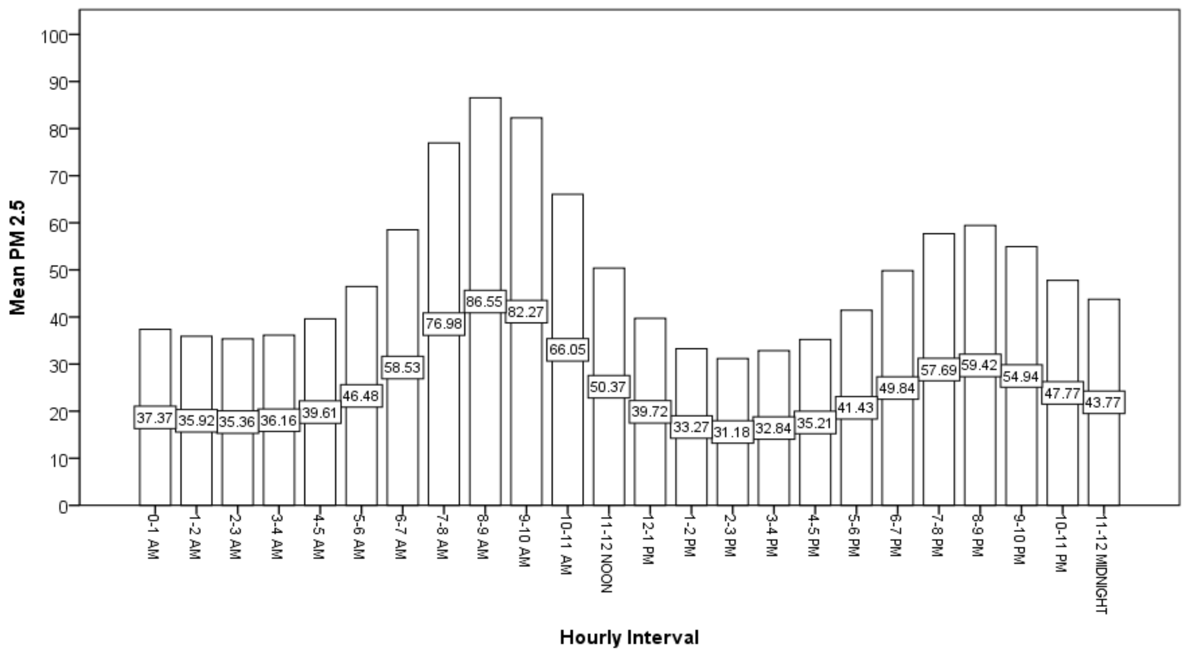


Figure 22: $PM_{2.5}$ assessment of hourly intervals for all stations

Interpretation / Assessment

Low levels are recorded from midnight to just before dawn, and these increase throughout the morning, reaching a peak from 8-9 AM (87). Levels then decline steeply to reach their lowest value (31) during 2-3 PM. Thereafter levels increase gradually and attain a high (59) at 8-9 PM, before gradually decreasing late at night. Overall, there exists a cyclical pattern as seen in the three-hourly interval averages. Ambient $PM_{2.5}$ values are the highest during the morning period (7-10 AM), with levels above 70. Prior to this period levels increase at an accelerating rate, which may be partly due to increasing human activity and in particular, increase in traffic density.

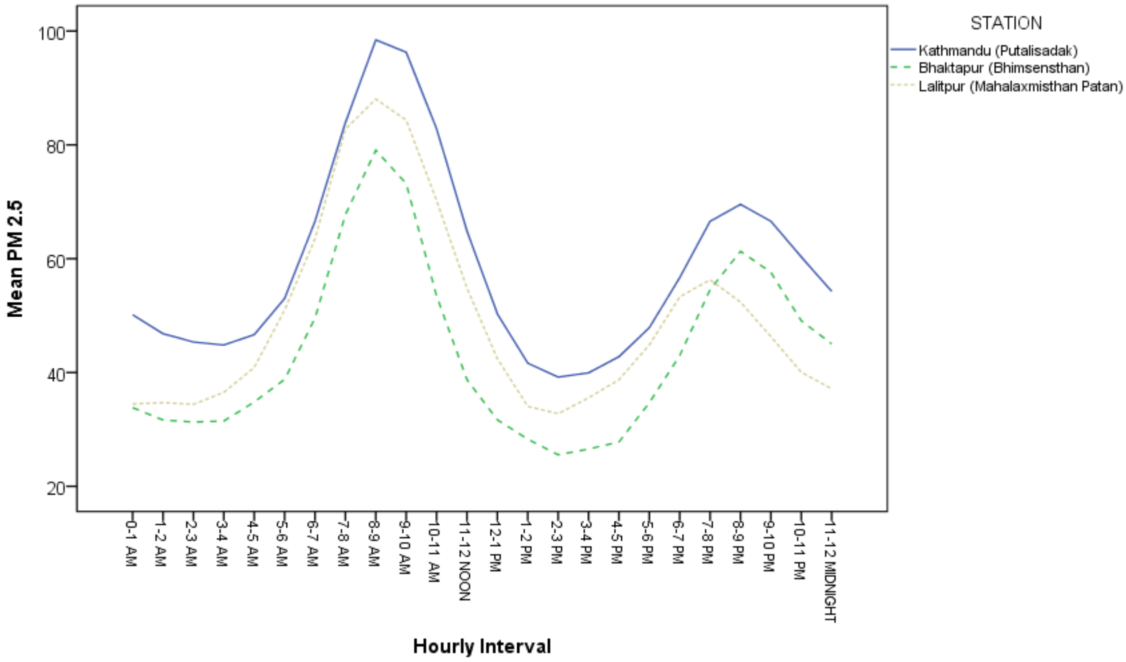


Figure 23: $PM_{2.5}$ assessment of hourly intervals between stations

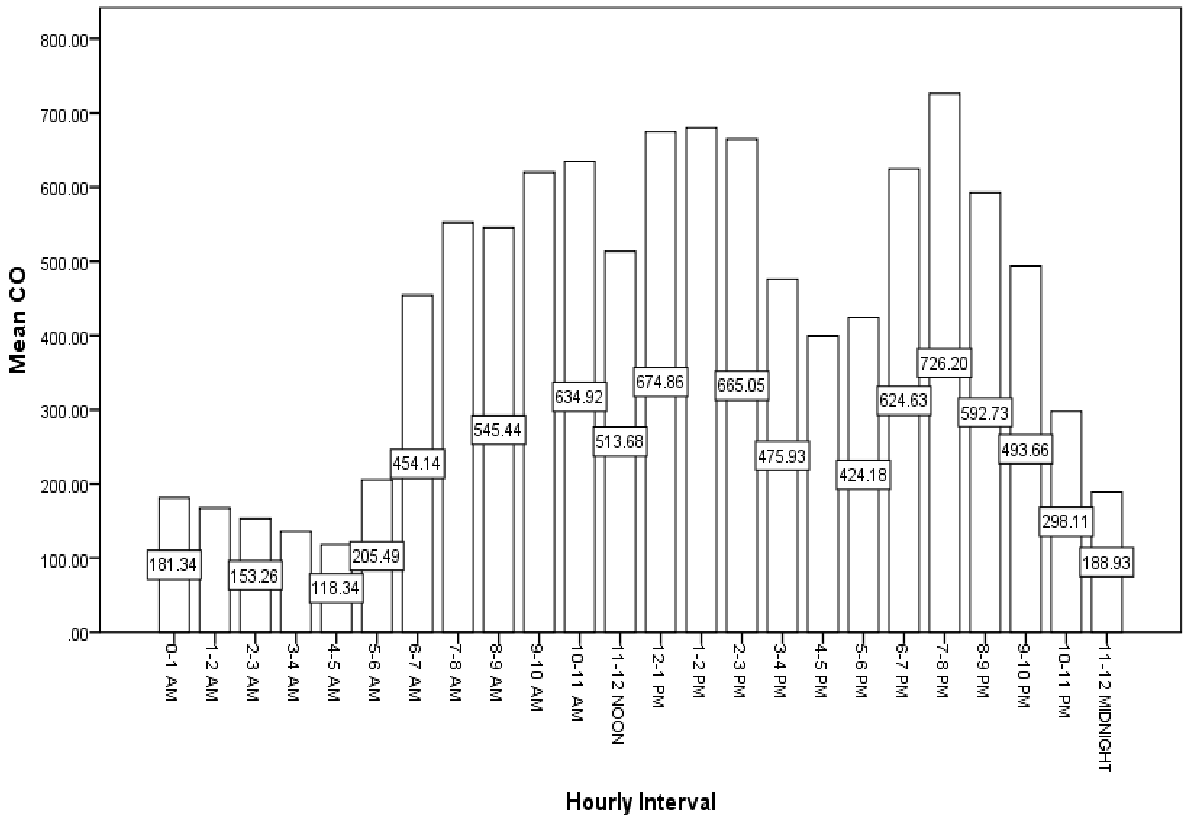


Figure 24: CO assessment of hourly intervals for all stations

Interpretation / Assessment

Hourly averages of CO are very low in the period after midnight and before dawn (less than 200) and start to increase during the early morning (5-6 AM), reaching around 635 from 10-11 AM. The level remains relatively high during the day until 2-3 PM (500-670) and decreases to around 400 by 4-5 PM. The level again increases to around 725 from 7-8 PM, and decreases thereafter through midnight (189), continuing to fall until just before dawn (118). The hourly recordings show lowest values from midnight through till before dawn, and are the highest from 12-3 PM and also at 7-8 PM, but all values are well below the 8-hour NAAQS of 10000. It can be said that in Kathmandu Valley CO ambient air pollution is acceptably low.

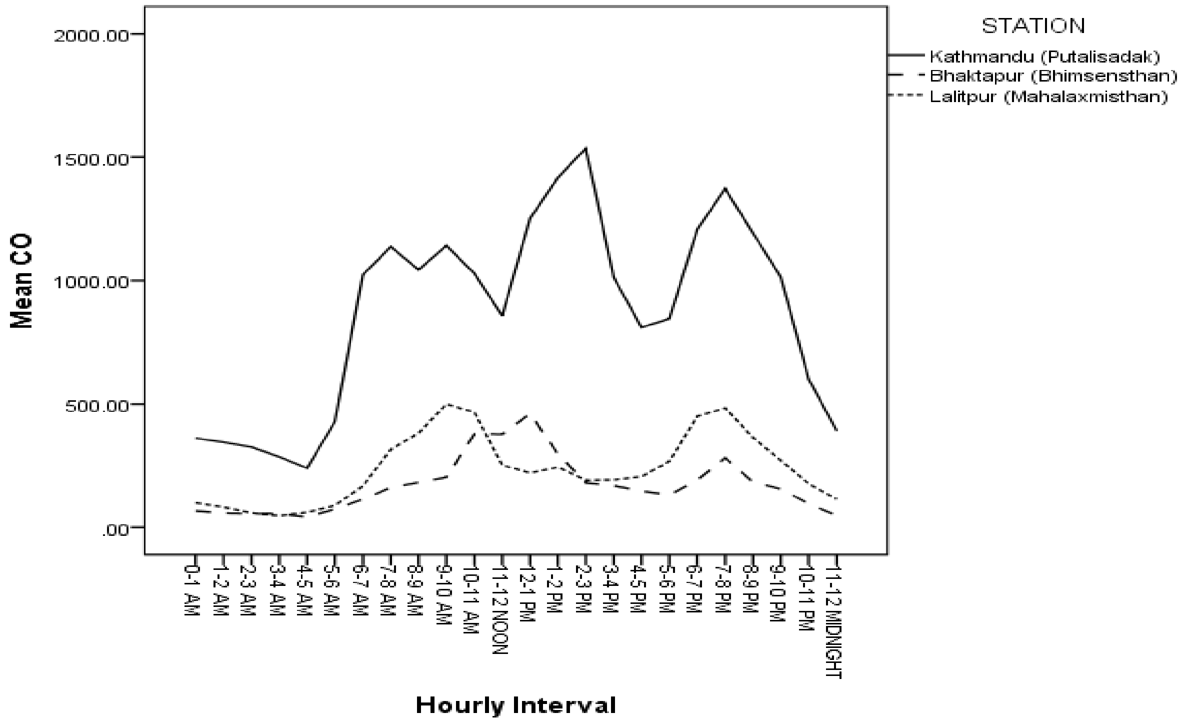


Figure 25: CO between-station hourly levels

Interpretation / Assessment

Station-wise comparison reveals that hourly CO averages are relatively much higher in Kathmandu than Lalitpur and Bhaktapur, as it was seen for the 3-hour averages. Figure 32 clearly indicates that ambient CO is much higher in Kathmandu when compared to the other two district stations. The recording of comparatively high values in Kathmandu may be due to higher traffic density in Kathmandu streets, even though averages are well below the 8 hour NAAQS standard.

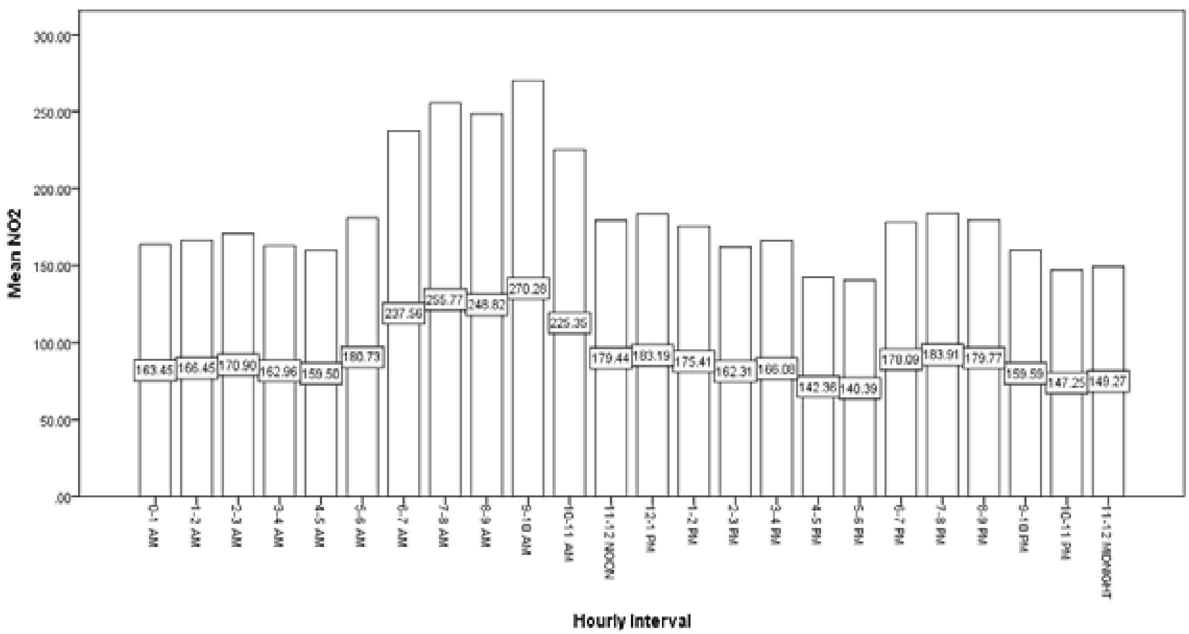


Figure 26: NO_2 hourly levels for all stations

Interpretation / Assessment

Hourly NO_2 averages show cyclical variation similar to $PM_{2.5}$ hourly variation. The averages are much higher than the 24-hour standard of 80, which reveals that Kathmandu Valley is highly polluted by ambient NO_2 pollution. Levels are relatively lower in the period after midnight and before dawn (160-170), and start rising in the early morning (5-6 AM). The levels rise to around 270 during 9-10 AM and start to decrease during the daytime to around 140 from 4-6 PM. The level again rises, to around 180, from 6-9 PM and then starts to decrease again till midnight (150).

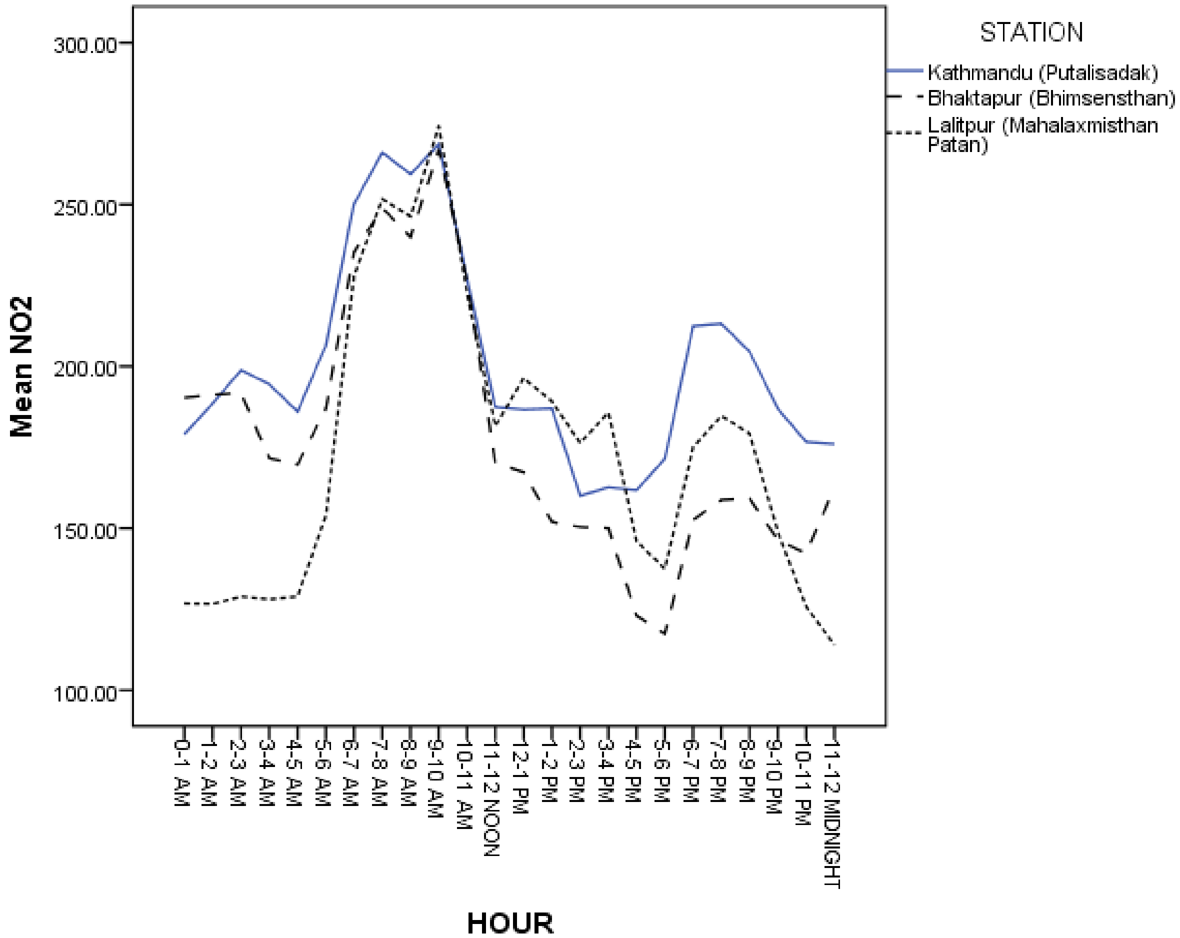


Figure 27: NO_2 between-station hourly levels

Interpretation / Assessment

If we examine the hourly averages between stations after midnight and before dawn (0-5 AM), we will find that the hourly averages of between 170 to 195 for both Kathmandu and Bhaktapur stations, with lower levels at Lalitpur station (125-130). Levels start to rise throughout the morning (5-6 AM) until 9-10 AM for all three stations, and reach around 270 for all the three stations at 9-10 AM. Levels then start to decrease at all the three stations and reach around 162 at 4-5 PM for Kathmandu station, around 117 at 5-6 PM at Bhaktapur station, and around 138 at 5-6 PM at Lalitpur station. During this period, Lalitpur station is at highest levels most of the time. After the fall in all three stations, levels again rise and reach around 213 at Kathmandu station at 7-8 PM, 160 at Bhaktapur station at 8-9 PM, and 185 at Lalitpur station at 7-8 PM. The levels again decrease thereafter at all the three stations. From 5-9 PM, hourly averages in Kathmandu are higher than the other two stations.

3.1.2.4 Eight hourly interval average CO levels

Table 20: Eight hourly interval average CO levels

Eight-hour interval	Mean	N	SD	CV
1-8 hour (midnight-morning)	246.0	487787	772.9	314.3
9-16 hour (morning-afternoon)	601.2	488136	4336.2	721.3
17-24 hour (afternoon-midnight)	468.5	491811	1255.6	267.9
total	438.7	1467734	2646.0	603.2

Interpretation / Assessment

Eight-hourly averages obtained from the whole year's data show that averages are the highest during morning to afternoon period and the lowest during the midnight to morning period.
CO is very high during the morning to afternoon period (720).

Figure 28: Between-station CO variation

Interpretation / Assessment

Evidently the 8-hour average is much higher at Kathmandu station compared to the other two stations. The 8-hour average is about five times higher in Kathmandu compared to Bhaktapur, while Bhaktapur is 1.4 times higher than Lalitpur.

3.1.3 Comparison between load shedding and normal time ($PM_{2.5}$)

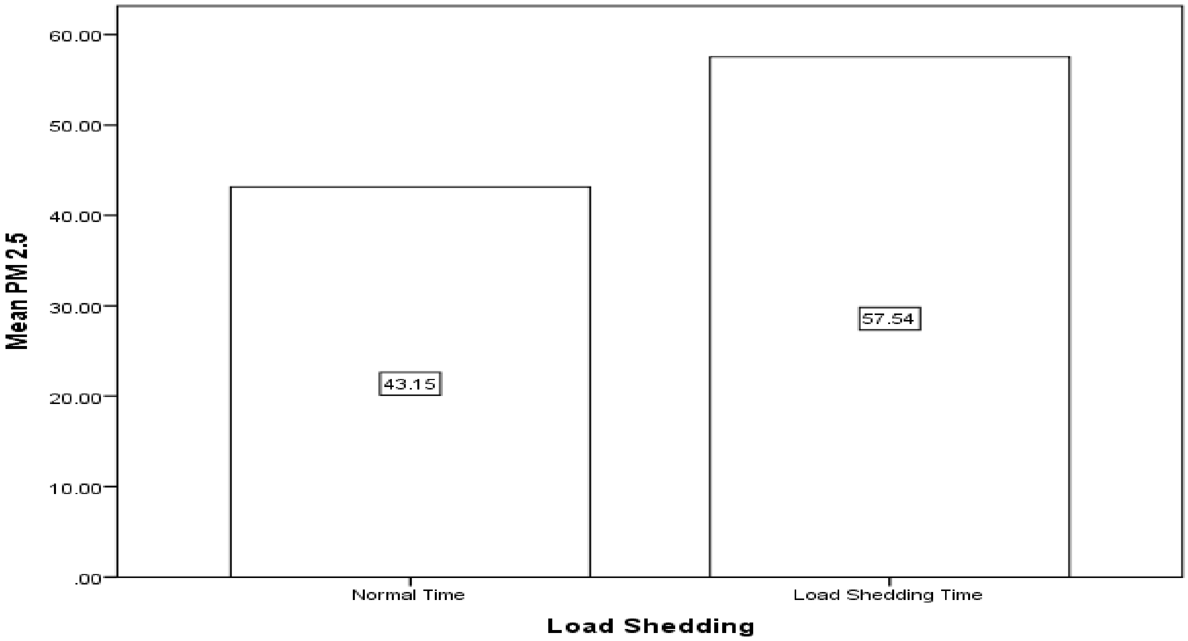


Figure 29: Comparison between load shedding and normal time ($PM_{2.5}$)

Interpretation / Assessment

$PM_{2.5}$ pollution in ambient air is found to be 1.33 times higher during scheduled power outage time. The higher levels of $PM_{2.5}$ during scheduled power outage time may be due to use of generators or other means of fuels which pollute the ambient air by emitting particulates.

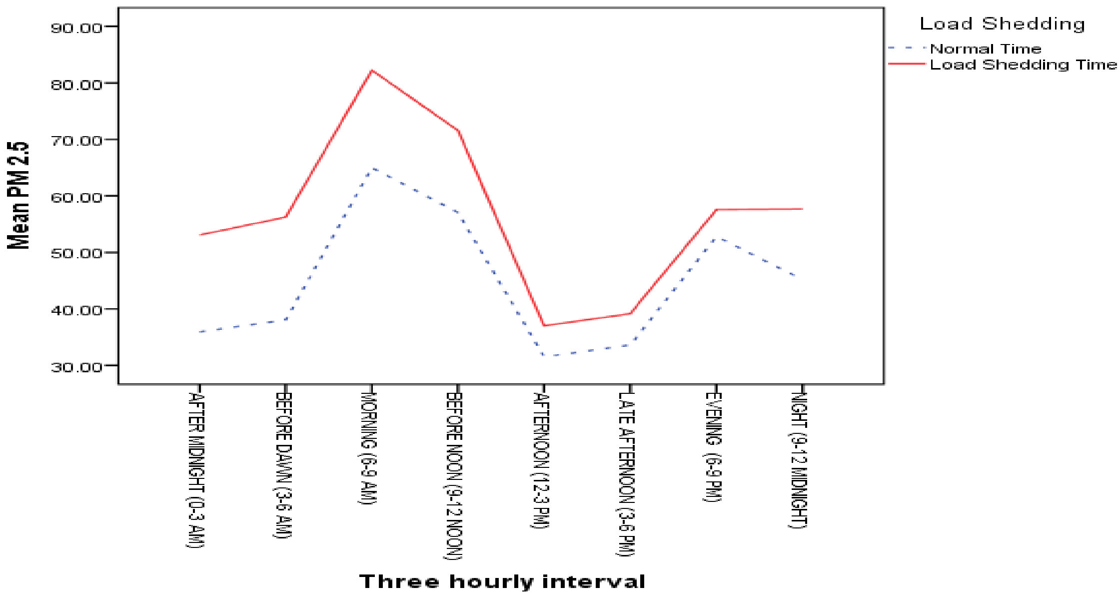


Figure 30: Comparison between load shedding and normal time ($PM_{2.5}$): Three-hourly intervals

Interpretation / Assessment

All three stations showed higher ambient $PM_{2.5}$ levels during scheduled power outage time compared to normal time when main electricity is available. The ratio of $PM_{2.5}$ for scheduled power outage time compared to normal time is the highest (1.36) in Lalitpur and the lowest in Kathmandu (1.28).

3.1.3.1 Station-wise comparisons

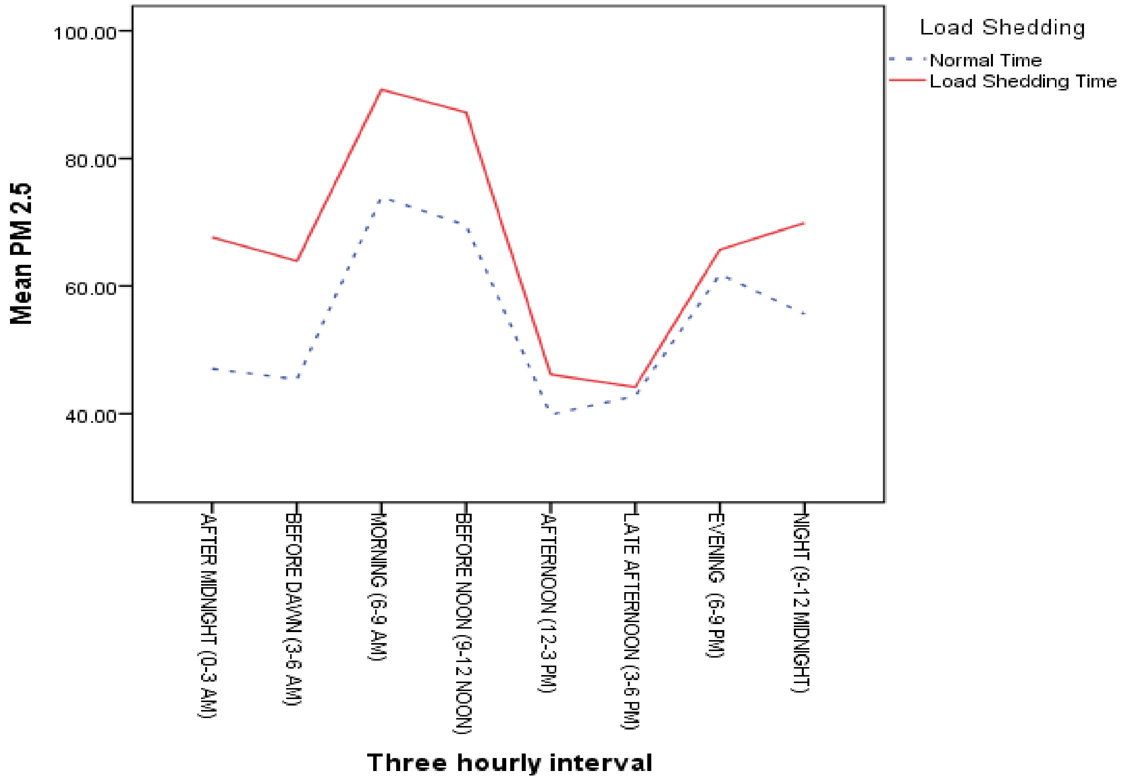


Figure 31: Station-wise comparison of $PM_{2.5}$ with load shedding at station 1

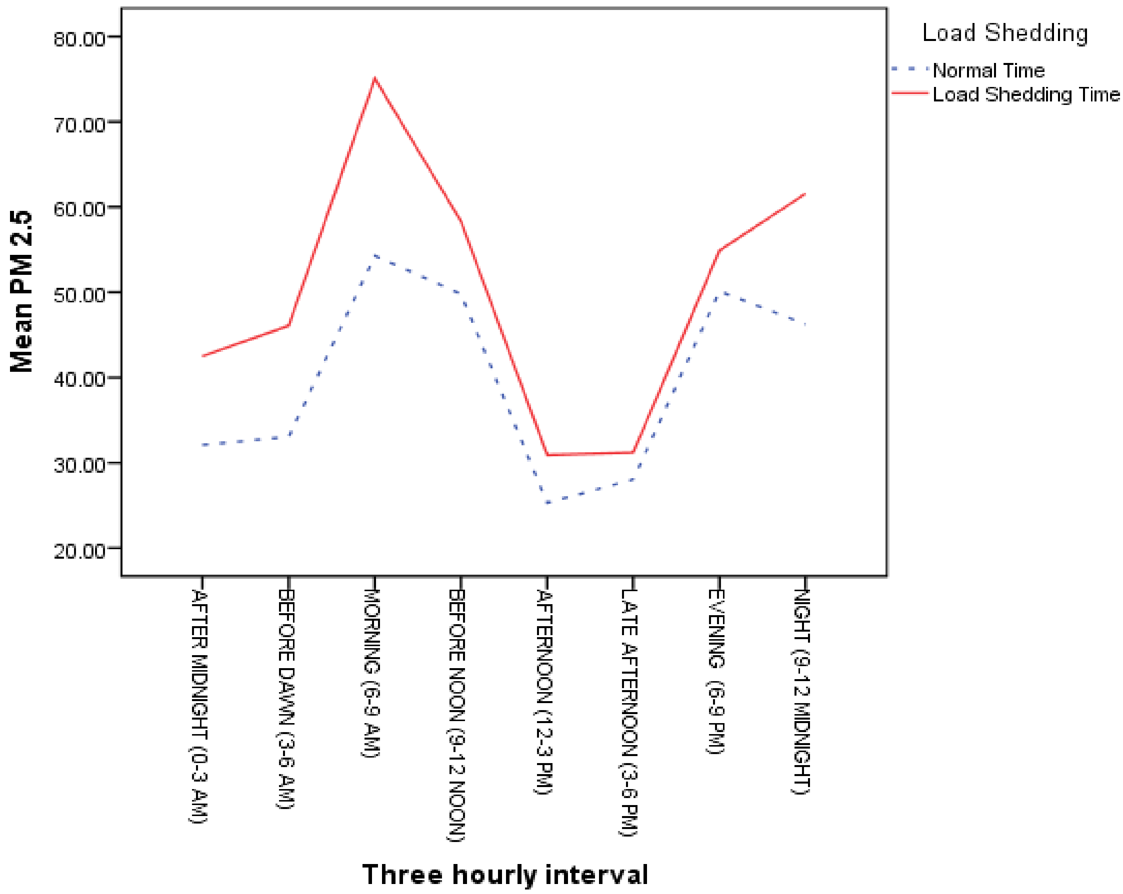


Figure 32: Station-wise comparison of $PM_{2.5}$ with load shedding at station 2

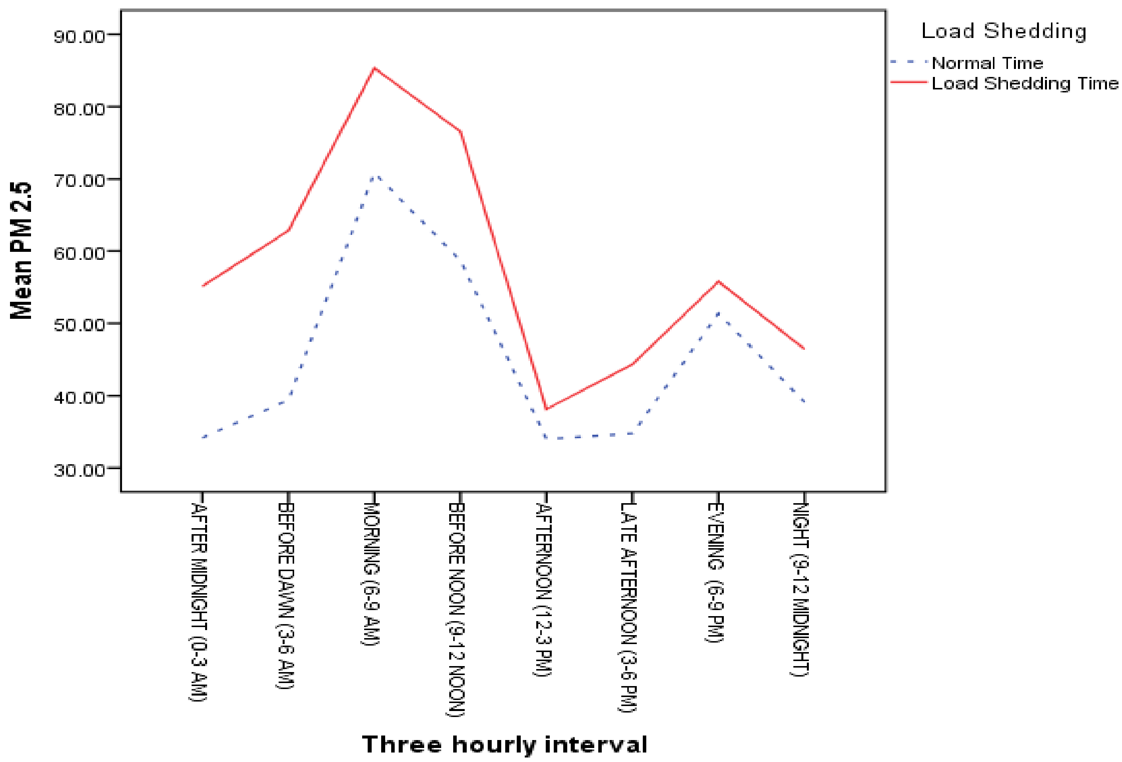


Figure 33: Station-wise comparison of $PM_{2.5}$ with load shedding at station 3

Interpretation / Assessment

At all stations three-hour averages of $PM_{2.5}$ levels were found higher during scheduled power outage time compared to normal time.

3.2 Descriptive analysis of health effects

Hospital morbidity as assessed by inpatient numbers is analyzed descriptively in this section. Changes in their occurrence are depicted based on the following factors:

- Hospitalizations in different hospitals
- Disease-wise hospitalizations
- Age-sex-wise distribution of inpatients
- Disease-wise mean age of inpatients
- District-wise distribution of inpatients
- Distribution of ARI inpatients
- Seasonal variation
- Monthly variation

3.2.1 Hospitalizations in different hospitals

The distribution of respiratory hospitalizations (total and all-inclusive) in different hospitals is shown below.

Table 21: The distribution of respiratory hospitalizations in different hospitals

Hospital	Frequency	Percent	Cumulative Percent
Bir Hospital	971	8.6	8.6
Kanti children's Hospital	817	7.2	15.8
TU Teaching Hospital	1842	16.3	32.1
B&B Hospital	554	4.9	37.0
Kathmandu Medical College (KMC) Teaching Hospital	977	8.6	45.6
Kathmandu Model Hospital	799	7.1	52.6
Ishan Hospital	372	3.3	55.9
Bhaktapur Hospital	217	1.9	57.8
OM Hospital	1582	14.0	71.8
Nepal Medical College (NMC) Teaching Hospital	927	8.2	80.0
Civil Hospital	103	0.9	80.9
Patan Hospital	1701	15.0	95.9
Siddhi Memorial Hospital	459	4.1	100.0
Total	11321	100.0	

Interpretation / Assessment

Three hospitals (TUTH, Patan and OM) recorded the highest numbers of respiratory inpatients (more than 1500 each) during the study time period (2070-71), while six hospitals had inpatient numbers ranging from 500 to 1000, and four hospitals (Siddhi, Bhaktapur, Ishan and Civil) recorded less than 500 inpatients each, giving a total of 11321 inpatients for the study period. TUTH had the highest number of respiratory inpatients (1842) and civil hospital had the lowest number (103). The mean number of inpatients in the monitored year was 871 with SD 556 (CV =63.8), i.e. variation between hospital inpatients is rather high.

3.2.2 Disease-wise hospitalizations

The distribution of disease-wise inpatients is shown below

Table 22:Disease-wise hospitalizations

Disease	Frequency	Percent	Cumulative Percent
COPD	4463	39.4	39.4
Pneumonia	3292	29.1	68.5
Asthma	548	4.8	73.3
Bronchitis	539	4.8	78.1
ARI	1733	15.3	93.4
Respiratory Symptom	92	0.8	94.2
Otitis Media	202	1.8	96.0
TB	76	0.7	96.7
Pleural Effusion	214	1.9	98.6
Chest Infection	46	0.4	99.0
CA Lungs	19	0.2	99.1
CA	29	0.3	99.4
Others	68	0.6	100.0
Total	11321	100.0	

Interpretation / Assessment

Among the considered diseases, COPD (4463), pneumonia (3292) and ARI (1733) excluding pneumonia were the leading respiratory diseases in Kathmandu Valley hospitals. Asthma (548), bronchitis (539), otitis media (202) and pleural effusion (214) also showed relatively substantial numbers of inpatients (200-550). Other diseases (as stated in the table above) had relatively fewer (less than 100) inpatients.

3.2.3 Age-sex-wise distribution of respiratory hospital inpatients

Distribution of hospital inpatients by age and sex is given below.

Table 23: Age-sex-wise distribution of respiratory hospital inpatients

Age Group	SEX				Total	
	Female		Male			
	Number	%	Number	%	Number	% of Total
0-9	1003	8.9%	1863	16.6%	2866	25.5%
10-19	233	2.1%	342	3.0%	575	5.1%

20-29	291	2.6%	240	2.1%	531	4.7%
30-39	213	1.9%	214	1.9%	427	3.8%
40-49	356	3.2%	261	2.3%	617	5.5%
50-59	656	5.8%	468	4.2%	1124	10.0%
60-69	1094	9.7%	925	8.2%	2019	18.0%
70-79	1029	9.2%	943	8.4%	1972	17.6%
80-89	501	4.5%	441	3.9%	942	8.4%
90-99	79	0.7%	64	0.6%	143	1.3%
100+	5	0.0%	1	0.0%	6	0.1%
Total	5460	48.7%	5762	51.3%	11222	100.0%

Missing cases excluded

Interpretation / Assessment

Comparative assessment between different age groups shows that children (0-9) and aged persons (50 or above) are the most vulnerable groups with regards to respiratory ailments. About 25.5% of patients are children and around 55% are aged persons. Only around 20% of inpatients belonged to the young/middle aged group (10-49). Gender-wise, male inpatients were slightly more common (51.3 %) than female inpatients. However, statistical tests show that there exist heterogeneous distributions between males and females in different age groups (chi-square test and contingency coefficients are highly significant with *p* values nearly equal to zero).

3.2.4 Diseasewise mean age of inpatients

The disease-wise mean age and standard deviations of inpatients and analysis of variance are given below.

Table 24: Diseasewise mean age of inpatients

Morbidity	Mean Age	N	SD	Minimum	Maximum
COPD	65.6	4388	15.5	0	105
Pneumonia	39.7	3286	29.6	0	99
Asthma	38.7	547	26.8	0	99
Bronchitis	37.9	539	31.5	0	100
ARI	7.4	1727	15.5	0	99
Respiratory Symptom	5.2	92	14.5	0	74
Otitis Media	25.3	202	11.8	6	82
TB	46.8	76	22.2	6	86
Pleural Effusion	41.1	214	27.8	0	97
Chest Infection	51.9	46	26.3	0	88
Lungs cancer	59.7	19	14.4	27	81
Cancer	65.1	29	12.1	28	81
Others	41.4	68	29.7	0	90
Total	44.4	11233	30.3	0	105

Interpretation / Assessment

Mean age is the highest among COPD inpatients (65.6) and the lowest among ARI patients with respiratory symptoms (5-7.5). Mean age is around 40 years for several diseases such as pneumonia, asthma, bronchitis, pleural effusion and diseases classified as others. High mean ages are also observed for diseases like TB, chest infection, and cancer inpatients (45-65).

Table 25: ANOVA table

Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Diseases	4682861.099	12	390238.425	780.794	.000
Within Diseases	5607720.481	11220	499.797		
Total	10290581.580	11232			

Interpretation / Assessment

One-way ANOVA demonstrates that mean age of inpatients is highly statistically significant (different) between types of diseases with p-value just above zero.

3.2.5 District wise distribution of inpatients

Table 26: District wise distribution of inpatients

Location	Frequency	Percent	Valid Percent	Cumulative Percent
Kathmandu	5058	44.7	45.0	45.0
Bhaktapur	1151	10.2	10.2	55.3
Lalitpur	1165	10.3	10.4	65.7
Outside Kathmandu Valley	3856	34.1	34.3	100.0
Total	11230	99.2	100.0	
Missing (Address not stated)	91	.8		
Corrected Total	11321	100.0		

Interpretation / Assessment

Out of the total inpatients, 65.7% were from Kathmandu valley and 34.3% were from outside Kathmandu valley. Among Kathmandu valley residents, the majority of inpatients had addresses in Kathmandu district (45%).

3.2.6 Distribution of ARI inpatients

The distribution of ARI inpatients according to different diseases is given below.

Table 27: Distribution of ARI inpatients

Disease	Frequency	Percent	Cumulative Percent
Not ARI	6181	54.6	54.6
Lower	416	3.7	58.3
Upper	55	0.5	58.8
Unspecified	1192	10.5	69.3
Pneumonia	3293	29.1	98.4
Tonsillitis	70	0.6	99.0
Ottitis Media	111	1.0	100.0
Sinusitis	2	0.0	100.0
Common Cold	1	0.0	100.0
Total	11321	100.0	

Interpretation / Assessment

Among the total inpatients, ARI inpatients comprise about 45.4%. Among total inpatients, 29.1% are pneumonia inpatients. Unspecified ARI cases also make up a substantial proportion (10.5%).

3.2.7 Seasonal variation

The seasonal changes in respiratory hospitalizations are shown below.

Table 28: Seasonal variation in hospitalizations

Diseases	Spring		Summer		Autumn		Winter		Total
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
COPD	1467	32.9	1100	24.6	4463	19.9	1008	22.6	4463
Pneumonia	930	28.3	866	26.3	3292	23.7	716	21.7	3292
Asthma	152	27.7	127	23.2	548	30.7	101	18.4	548
Bronchitis	126	23.4	160	29.7	539	24.3	122	22.6	539
ARI	410	23.7	466	26.9	1733	28.1	370	21.4	1733
Respiratory Symptom	3	3.3	8	8.7	92	77.2	10	10.9	92
Otitis Media	58	28.7	50	24.8	202	26.7	40	19.8	202
TB	39	51.3	22	28.9	76	17.1	2	2.6	76
Pleural Effusion	46	21.5	51	23.8	214	32.2	48	22.4	214
Chest Infection	7	15.2	8	17.4	46	39.1	13	28.3	46
Lung cancer	0	0.0	0	0.0	19	21.1	15	78.9	19
Cancer	0	0.0	0	0.0	29	0.0	29	100.0	29
Others	23	33.8	16	23.5	68	27.9	10	14.7	68
Total	3261	28.8	2874	25.4	11321	23.9	2484	21.9	11321

Interpretation / Assessment

There is a trend of steady decreasing seasonal patient from spring to winter for both total cases and cases from Kathmandu Valley. This is perhaps a typical result relevant only to the monitored year, as winter months in the past have seen greater numbers of respiratory inpatients. It may be due to under reporting in this monitored year however, there is strong association between pollution level and respiratory illness. The disease-wise seasonal changes are shown in the table below. COPD morbidity is recorded the highest during spring and the lowest in autumn. Similarly, pneumonia inpatient numbers are the highest in spring and the lowest in winter. Conversely, ARI is found to be most common in autumn and lowest in winter. These figures suggest that no single pattern describes all disease prevalence. A chi-square test and contingency coefficient demonstrate that seasonal variation between diseases is statistically significant, with *p*-values nearly equal to zero (Cancer cases were excluded due to low frequency).

3.2.8 Monthly variation

The monthly changes in respiratory hospitalizations and their correlations with weather variables are shown below.

Table 29: Monthly variation in hospitalizations

Month	COPD	Pneumonia	Asthma	Bronchitis	ARI	Otitis Media	TB	Pleural Effusion	Total
Falgun 2070	478	326	54	24	123	27	16	18	1066
Chaitra 2070	510	306	54	44	194	14	12	15	1149
Baishak 2071	479	298	44	58	93	17	11	13	1013
Jestha 2071	481	386	42	80	158	13	6	12	1178
Ashad 2071	324	268	35	48	172	23	7	12	889
Shrawan 2071	295	212	50	32	136	14	9	27	775
Bhadra 2071	306	246	84	48	162	18	6	21	891
Aswin 2071	306	284	58	49	214	11	4	24	950
Kartik 2071	276	250	26	34	111	25	3	24	749
Manshir 2071	281	250	27	40	134	13	0	26	771
Poush 2071	379	275	48	58	110	4	2	11	887
Magh 2071	348	191	26	24	126	23	0	11	749
Total	4463	3292	548	539	1733	202	76	214	11067

Interpretation / Assessment

Monthly cases of respiratory disease inpatiants for the monitored year are found to peak in Jestha and reach minimum in Magh. Warm months recorded more repiratory inpatients than cold months.

Table 30: Correlations (monthly) of respiratory hospitalizations with pollution and metrological parameters.

Disease	$PM_{2.5}$	CO	NO_2	Temperature	Relative Humidity	Rainfall
Respiratory	.088	-.466	-.078	.270	-.562	-.224
Respiratory (Address KTM valley)	.043	-.480	-.103	.283	-.559	-.198
ARI	-.215	-.606*	-.355	.471	-.269	-.016
ARI (Address KTM valley)	-.217	-.527	-.303	.475	-.290	-.059
COPD	.446	-.152	.371	-.032	-.788**	-.606*
COPD (Address KTM valley)	.445	-.168	.395	-.049	-.838**	-.609*
Pneumonia	.090	-.475	-.069	.233	-.478	-.334
Pneumonia (Address KTM valley)	.126	-.395	-.004	.172	-.425	-.447
Respiratory_Age≤19	-.485	-.534	-.632*	.319	.311	.505
Respiratory_Age≤19 (Address KTM valley)	-.508	-.582*	-.629*	.407	.174	.507
Respiratory_Age≥50	.401	-.254	.255	.017	-.716**	-.467
Respiratory_Age≥50 (Address KTM valley)	.414	-.240	.296	.009	-.797**	-.511

For Kathmandu valley addresses only:

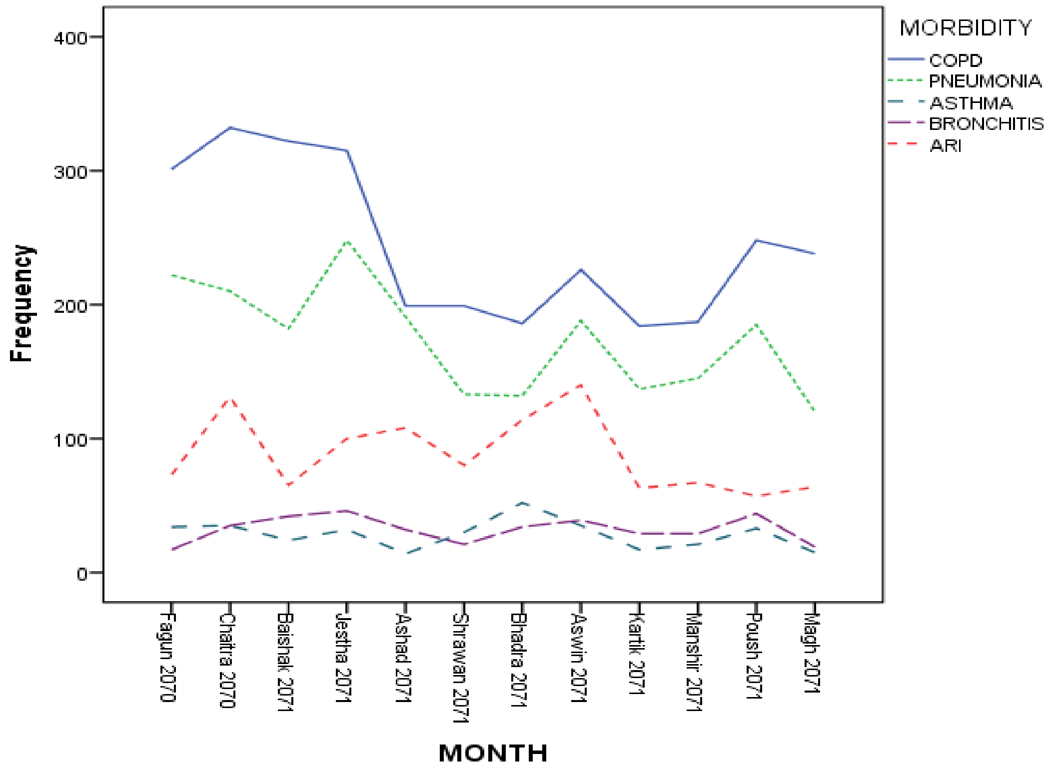


Figure 34: Monthly variation of respiratory hospitalizations with pollution and metrological parameters.

Interpretation / Assessment

Correlations between monthly inpatient numbers and averages of pollution and weather parameters were examined. $PM_{2.5}$ concentration is positively correlated with most diseases considered, whereas CO and NO_2 monthly means are negatively associated with respiratory hospitalizations (barring a few exceptions for NO_2). Temperature is found to be positively associated with all respiratory diseases except for COPD. Rainfall and relative humidity is found negatively associated with respiratory hospitalizations, with the exception of hospitalozations of children and adolescents. Most of the correlations are not statistically significant, raising doubts as to the meaningfulness of the observed correlations.

3.3 Statistical models of health effects

The health effects which can be attributed to ambient air pollution in Kathmandu Valley have been assessed by respiratory morbidity, reported as hospitalizations, and by mortality, assessed by all-cause non-accidental deaths in the leading hospitals within the valley. Statistical modeling is the principal analytical tool for establishing linkages between health problems due to ambient air pollution, along with accounting of confounding variables like weather changes etc. Statistical modeling through generalized linear models (GLMs) or generalized additive models (GAM) based upon daily hospitalizations (or deaths) and daily changes in weather parameters has been considered appropriate for establishing linkages and estimating the percentage changes in morbidity (or mortality) that can be attributed to unit (or some prefixed value) changes in ambient air pollution. In order to fulfill this objective, daily data has been collected for various potential relevant variables as given below.

Table 31: Statistical models of health effects

Response Variables	Main Explanatory Variables	Confounders
Respiratory hospitalizations (All respiratory ailments including chest, lungs, Cancer, TB, etc.)	Ambient $PM_{2.5}$	Air temperature
COPD hospitalizations	Ambient CO	Relative humidity
ARI hospitalizations	Ambient NO_2	Rainfall
Pneumonia hospitalizations		Season
Age-specific respiratory hospitalizations		Day of week (Saturday)
Address-specific hospitalizations		
All-cause mortality (non-accidental)		

Statistical models incorporating multiple ambient air pollutants have been used with weather variables like temperature, relative humidity and rainfall. Additionally, since hospitalizations and deaths have been found to be strongly correlated with day of week (mainly the weekly holiday of Saturday), it has also been explored for inclusion in the models. In past studies, it has been found that distributed lag effects of ambient air pollution and confounders like several past days mean, geometric lag effect, etc. have also been statistically significant as explanatory variables. Given this information, distributed lag effect (short term) has also been explored and incorporated into models when suitable. The main different schemes or functional forms of lag effects explored are as follows. Other functional forms can also be explored and are left for further research work.

- Same day effect
- Mean effect of same and past days effect (2 day, 4 day, week, two weeks, etc)
- Geometrical lag effect (4 day, week, two week, etc.)
- Arithmetical lag effect (4 day, week, two week, etc.)

Statistical models developed are separately presented in different sub-sections with different responses. Only the final selected statistical models are presented after rigorous exploration of different combinations of predictors including different forms of with and without lag structures of the explanatory variables. Models are screened with different main model adequacy measures, namely goodness of fit, normality, heteroscedasticity, multicollinearity, autocorrelation and outliers (distinctly separated with high standardized residual values). Corrected models are also generated with additional lagged dependent variables under autocorrelation problem, which is likely given models are based upon time series data. Upon examination, slight autocorrelation problems do exist with all the developed models for morbidity hospitalizations. As such, two models are generated: one without lagged term(s) of hospitalizations and the other with lagged terms corrected for autocorrelation for morbidity hospitalizations. Both are considered since in all cases the autocorrelations detected are only slightly significant, and may therefore be ignored. Altogether 25 models were developed as described below.

Table 32: Models without lagged term of hospitalizations and lagged terms corrected for autocorrelation for morbidity hospitalizations

Model	All addresses included	Address Kathmandu Valley	Autoregressive (All addresses)	Autoregressive (Kathmandu address)	Total
Respiratory	1	1	1	1	4
COPD	1	1	1	1	4
ARI	1	1	1	1	4
Pneumonia	1	1	1	1	4
Respiratory (age≤19)	1	1	1	1	4
Respiratory age≥50)	1	1	1	1	4
All Cause mortality	1	0	0	0	1
Total	7	6	6	6	25

Fitted models were screened through various model adequacy measures as shown below.

Table 33: Fitted models were screened through various model adequacy measures

Detection	Method	Criteria	Preferred p value
Goodness of fit	Omnibus test	Statistical significance	<0.05
Normality	Kolmogorov-Smirnov (K-S) test	Statistical insignificance	>0.01
Multicollinearity	Variance inflation factors (VIFs)	Low value	< 5
Heteroscedasticity	Residual plot	Randomly distributed in constant band	-
Autocorrelation	Correlogram up to 7^{th} lag	Statistical insignificance	>0.01

3.3.1 Respiratory effect models

Respiratory effect models incorporate all respiratory hospitalizations. The models with and without autocorrelation corrected lagged terms are presented below. In total, four models were developed with respiratory hospitalization as the response variable.

3.3.1.1 Respiratory effect model (all addresses inclusive)

Table 34: Respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95%Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.404	.1492	3.112	3.697	520.940	1	.000
[Saturday=No]	.366	.0309	.305	.426	140.032	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0014	.0004	.001	.002	10.626	1	.001
Temperature_0	.0091	.0025	.004	.014	13.568	1	.000
Relative Humidity_0	-.0129	.0024	-.018	-.008	28.994	1	.000
Rainfall_0	-.0034	.0015	-.006	.000	5.206	1	.023
a. Set to zero because this parameter is redundant. 0 (lag) indicates same day effect							

Among the considered predictors, all same day effects are found to be statistically significant ($p<0.05$), which suggests that distributed lag effects are not needed for this respiratory hospitalization response model. Same day effects of $PM_{2.5}$, temperature, relative humidity and rainfall are found to be statistically significant with positive correlations for $PM_{2.5}$, temperature and non-Saturdays; and negative correlations for the remaining variables. The coefficients reveal the following relative risks and corresponding percent changes in respiratory admissions per unit (as indicated) increase in predictor values (or codes).Relative risks and percent increase are given below.

Table 35: Respiratory effect model (all addresses inclusive): Relative risks and percent increase

Predictor	Estimate	Difference	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0014	10	µg/m³	1.014	1.41
Temperature_0	0.0091	1	⁰ Celsius	1.009	0.91
Relative Humidity_0	-0.0129	1	%	0.987	-1.28
Rainfall_0	-0.0034	1	mm	0.997	-0.34
Not Saturday	0.366	1	Categorical	1.442	44.20

Table 36: Respiratory effect model (all addresses inclusive): Model adequacy tests

Particular	Values /Graph	Assessment
Goodness of fit	Null Deviance=1029.4 at 364 df; Residual Deviance:789.5 at 359 df Omnibus test: highly significant with log likelihood chi-square: (239.9 at 5 df; p <0.0001)	Good
Multicollinearity	VIFs <2.5	No multicollinearity
Heteroscedasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram	Slight significant autocorrelations at 1, 2, and 7 lags
Normality	K-S test for deviance residual with p = 0.35; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected

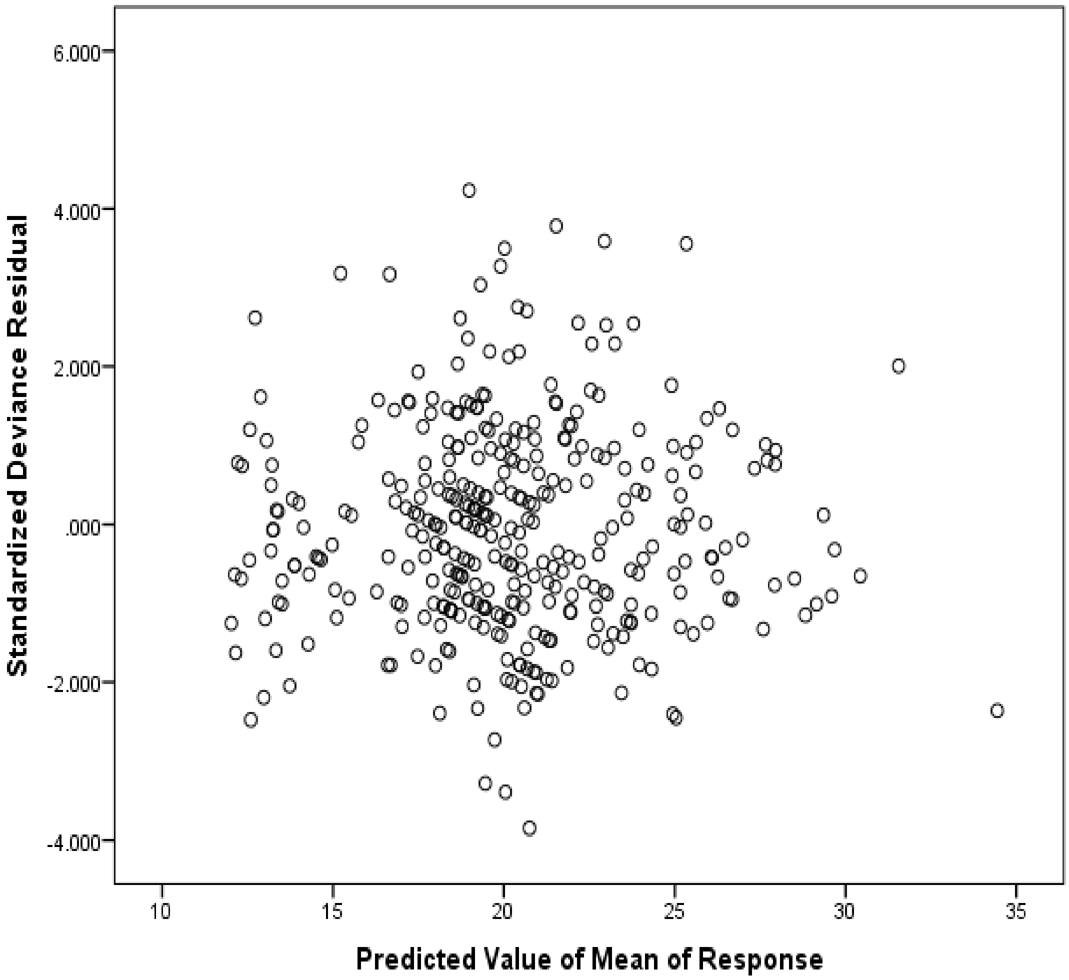


Figure 35: Respiratory effect model (all addresses inclusive): Model adequacy tests

3.3.1.2 Autoregressive respiratory effect model (all addresses inclusive)

The autoregressive GLM (autocorrelation corrected) is presented below.

Table 37: Autoregressive respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	**β**	**Std. Error**	**95%Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	2.750	.1735	2.410	3.090	251.234	1	.000
[Saturday=No]	.356	.0335	.290	.422	112.928	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$	.0010	.0005	3.767E-005	.002	4.164	1	.041
Temperature_0	.0064	.0025	.001	.011	6.497	1	.011
Relative Humidity_0	-.0058	.0026	-.011	-.001	4.980	1	.026
Rainfall_0	-.0034	.0015	-.006	.000	5.012	1	.025
Respiratory_1	.0053	.0011	.003	.007	24.962	1	.000
Respiratory_2	.0046	.0011	.003	.007	19.208	1	.000
Respiratory_7	.0041	.0011	.002	.006	13.426	1	.000
a. Set to zero because this parameter is redundant, 0=Same Day Lag, 1=1 Day Lag and so on							

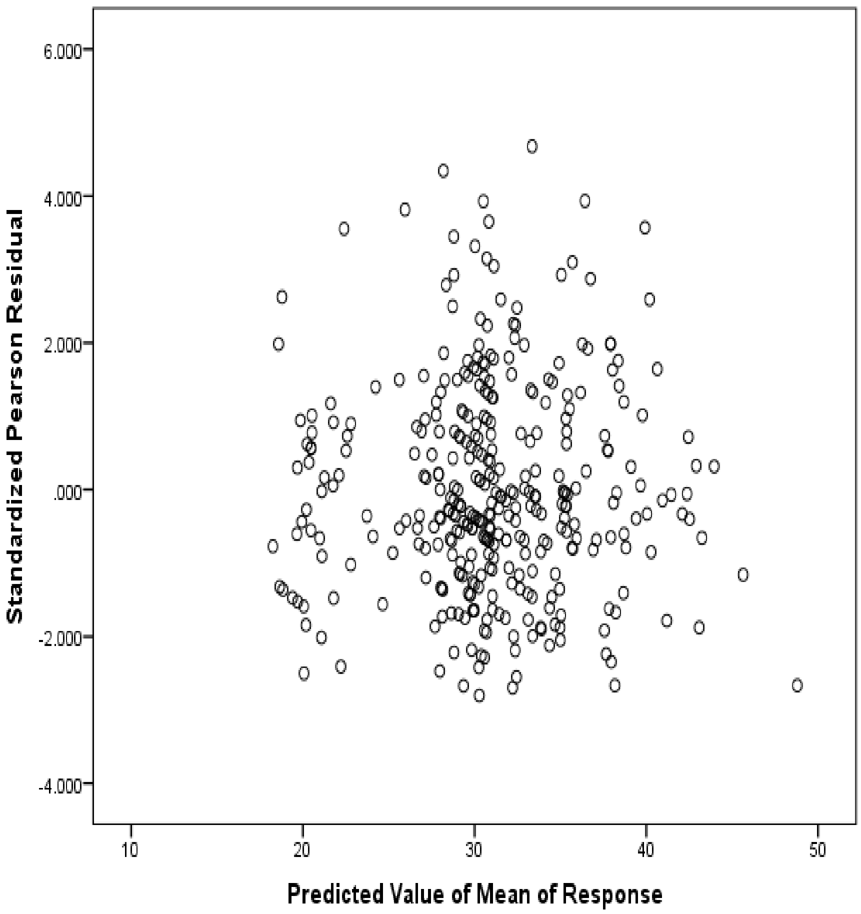
Three additional lagged terms of respiratory hospitalizations were added which reduce autocorrelations significantly, to produce an autocorrelation-corrected model. The coefficients reveal the following relative risks and corresponding percent changes in respiratory admissions per unit (as indicated) increase in predictor values (or codes). There are some changes in the coefficients compared to the model without autocorrelation correction, as seen in the table below.

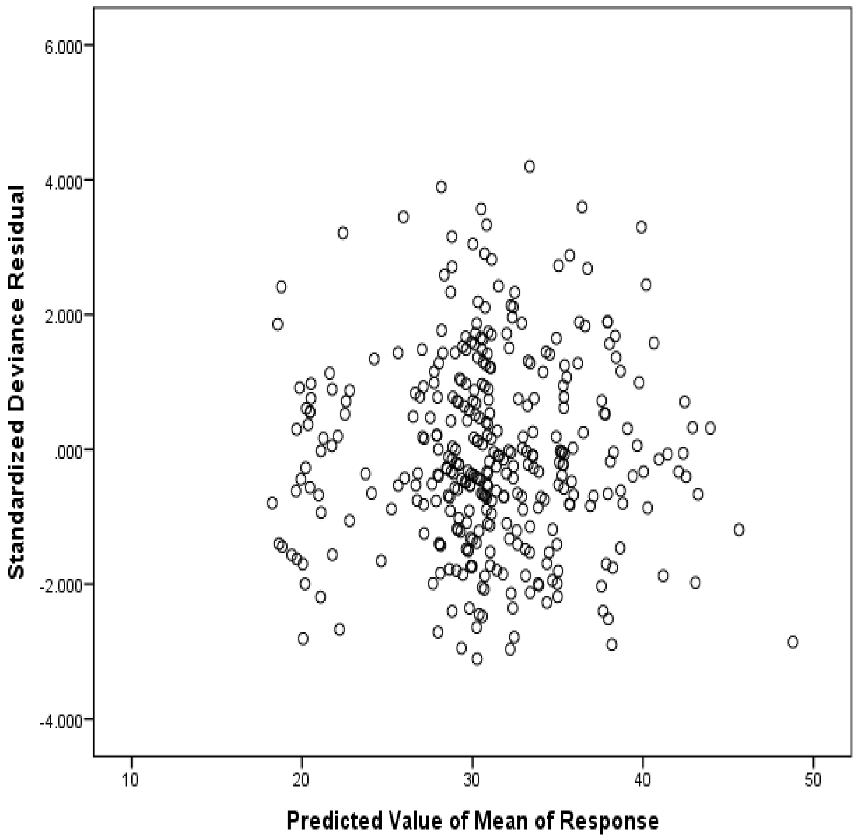
Table 38: Autoregressive respiratory effect model (all addresses inclusive): Relative risks and percent increase

Predictor	Estimate	Difference	Unit	RR	Percent Change
$PM_{2.5}$	0.0010	10	$\mu g/m^3$	1.010	1.01
Temperature	0.0064	1	^{0} Celsius	1.006	0.64
Relative Humidity	-0.0058	1	%	0.994	-0.58
Rainfall	-0.0034	1	mm	0.997	-0.34
Non-Saturdays	0.356	1	categorical	1.428	42.76

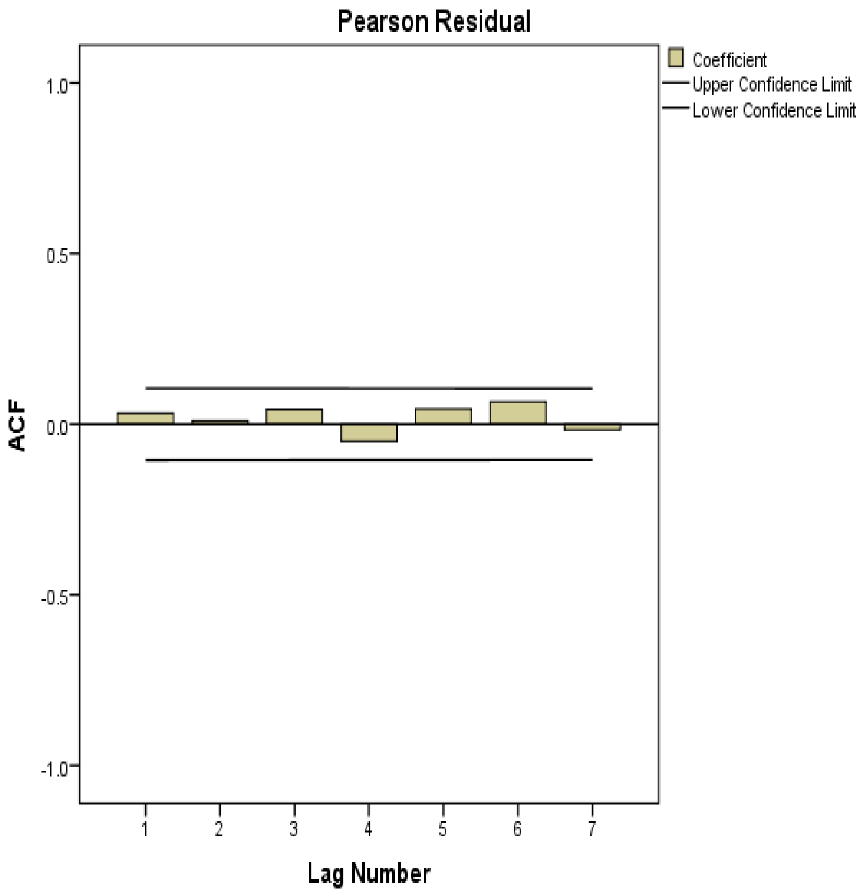
Table 39: Autoregressive respiratory effect model (all addresses inclusive): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=1021.4 at 357 df; Residual Deviance:695.4 at 349 df Omnibus test: highly significant with log likelihood chi-square: (325.9 at 8 df; p <0.0001)	Good
Multicollinearity	VIFs <2.7	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram up to 7th lag	Autocorrelations insignificant
Normality	KS test for deviance residual with p = 0.21; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected

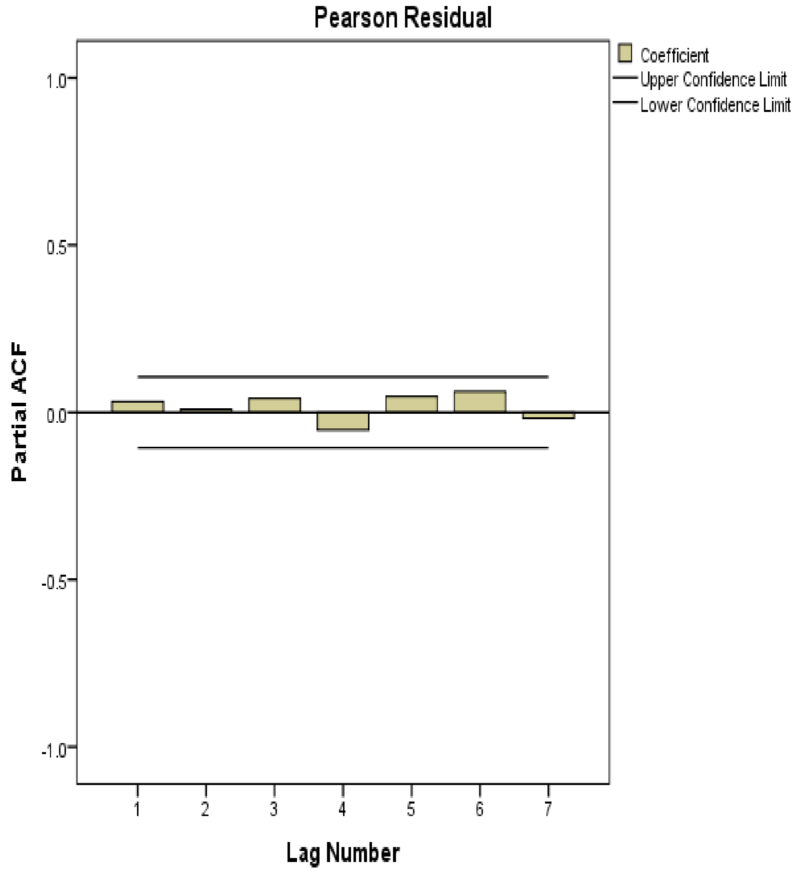




6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
10
20
30
40
50
Predicted Value of Mean of Response



Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
1.0
0.5
0.0
-0.5
-1.0
ACF
1
2
3
4
5
6
7
Lag Number


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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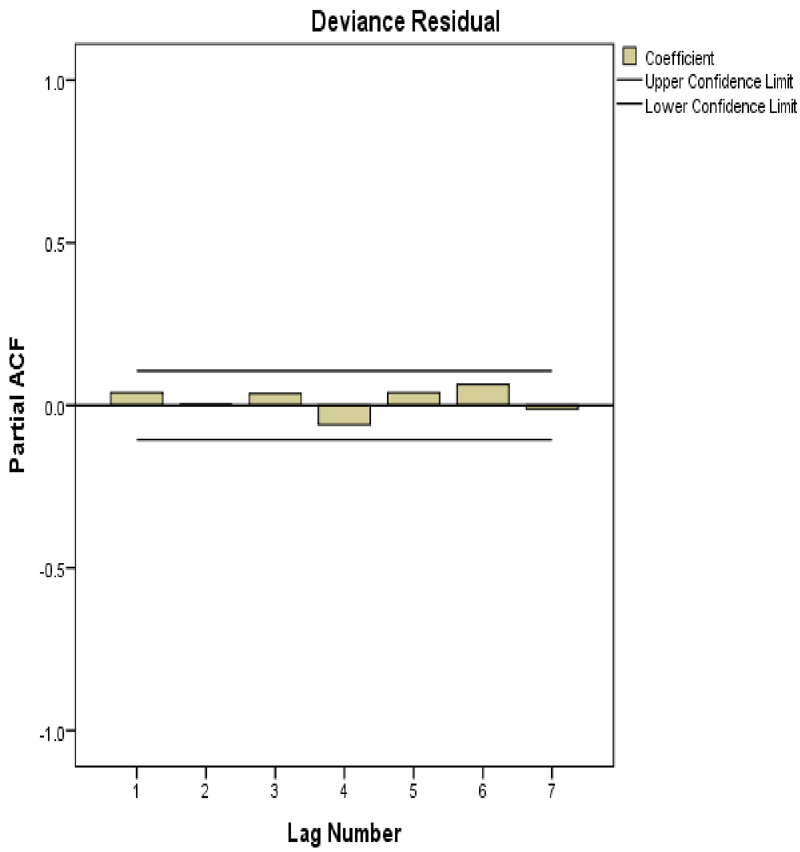
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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0.0
-0.5
-1.0
1
2
3
4
5
6
7
Lag Number

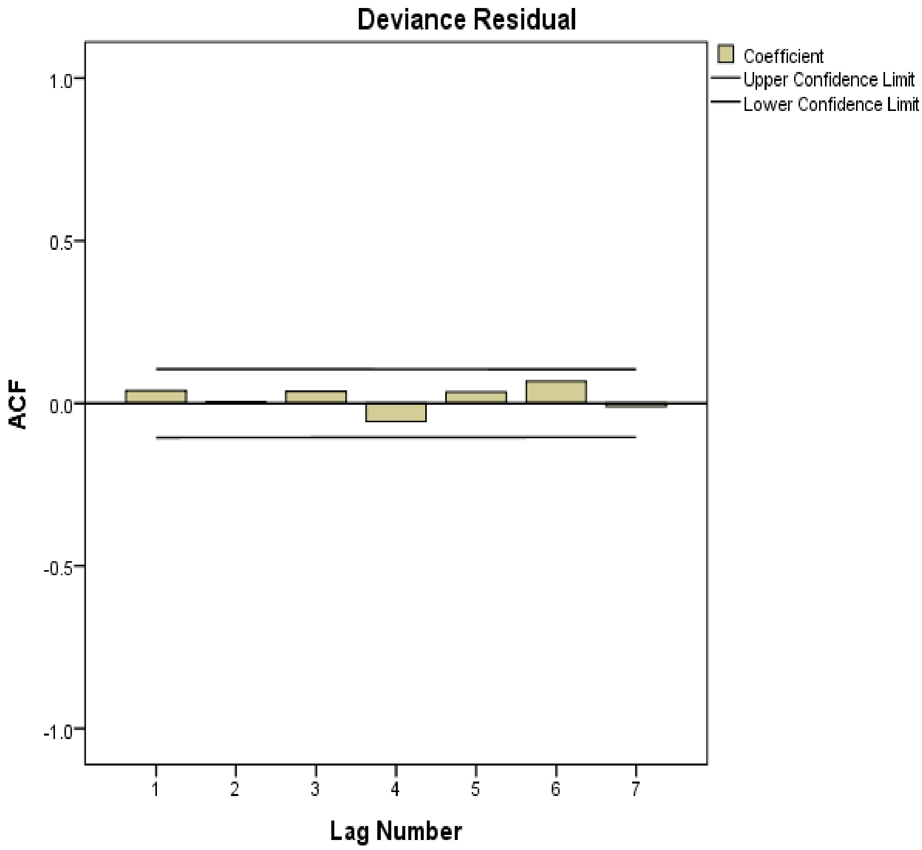


Figure 36: Autoregressive respiratory effect model (all addresses inclusive): Model adequacy tests

3.3.1.3 Respiratory effect model (address Kathmandu Valley only)

Analysis of data for morbidities of inpatients with addresses within Kathmandu Valley was done separately as follows. The model is presented below.

Table 40: Respiratory effect model (address Kathmandu Valley only)

Parameter Estimates							
Parameter	**β**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	3.083	.1845	2.722	3.445	279.384	1	.000
[Saturday=No]	.370	.0383	.295	.445	93.115	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0014	.0005	.000	.003	7.239	1	.007
Temperature_0	.0102	.0031	.004	.016	11.223	1	.001
Relative Humidity_0	-.0162	.0029	-.022	-.010	30.092	1	.000
Rainfall_0	-.0035	.0019	-.007	.000	3.399	1	.065
a. Set to zero because this parameter is redundant.							

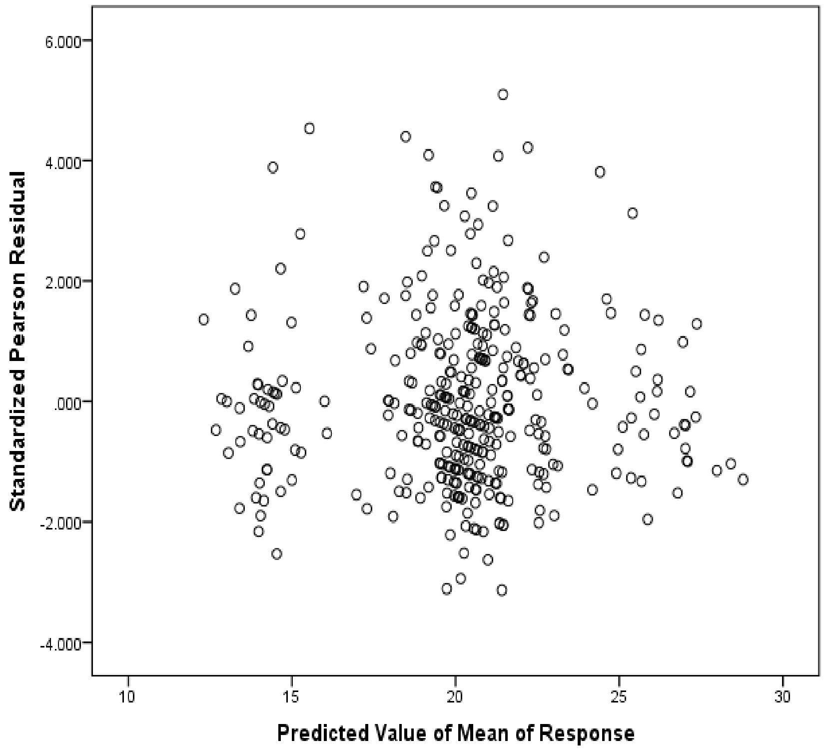
Among the considered predictors, same day effects are found to be statistically significant, which suggest that distributed lag effects are not needed with the respiratory hospitalization response model for Kathmandu residents either . Same day effects of $PM_{2.5}$, temperature, relative humidity and rainfall are found to be statistically significant with positive correlations for $PM_{2.5}$, temperature and non-Saturdays, and negative correlations for relative humidity and rainfall. The coefficients reveal the following relative risks and corresponding percent changes in respiratory admissions per unit (as indicated) increase in predictor values (or codes).
Relative risks and percent increases are given below.

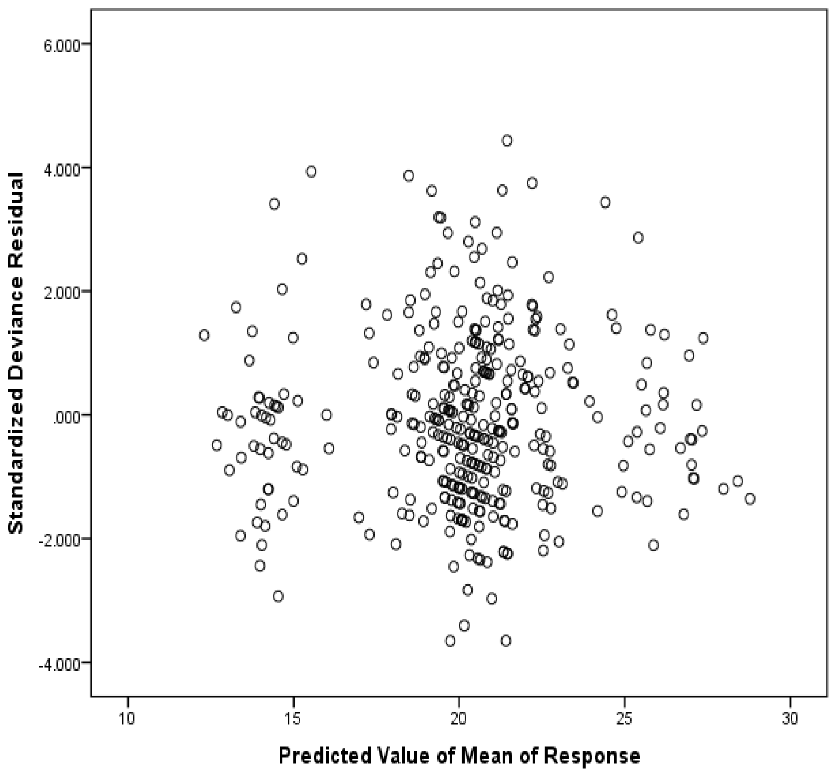
Table 41: Respiratory effect model (address Kathmandu Valley): Relative risks

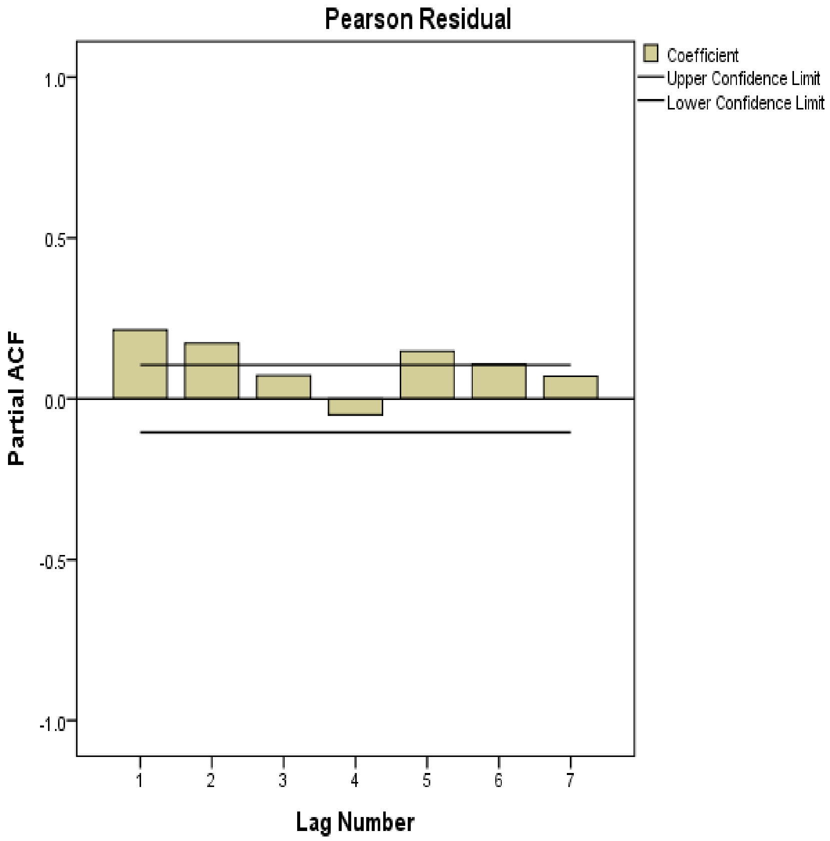
Predictor	Estimate	Difference	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0014	10	μg/m³	1.014	1.41
Temperature_0	0.0102	1	^{0} Celsius	1.010	1.03
Relative Humidity_0	-0.0162	1	%	0.984	-1.61
Rainfall_0	-0.0035	1	mm	0.997	-0.35
Non-Saturdays*	0.37	1	-	1.448	44.77
*Categorical variable					

Table 42: Respiratory effect model (address Kathmandu Valley): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=872.1 at 364 df; Residual Deviance:692.6 at 359 df Omnibus test: highly significant with log likelihood chi-square: (179.6 at 5 df; p <0.0001)	Good
Multicollinearity	VIFs <2.5	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram up to 7th lag	Slightly significant autocorrelations at 1, 2, 5 and 6 lags
Normality	KS test for deviance residual with p = 0.17; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Pearson Residual
10
15
20
25
30
Predicted Value of Mean of Response


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
10
15
20
25
30
Predicted Value of Mean of Response



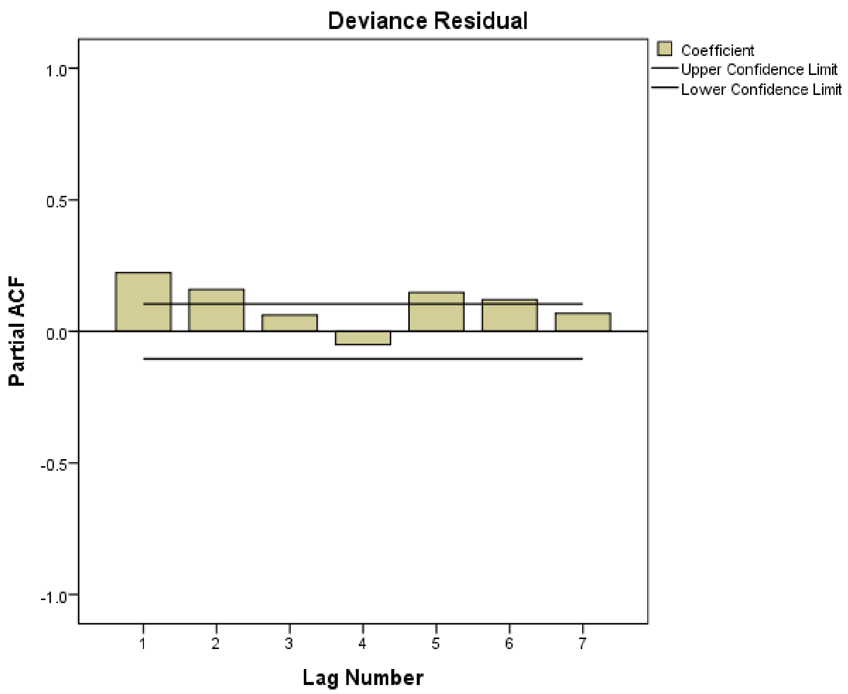


Figure 37: Respiratory effect model (address Kathmandu Valley): Model adequacy tests

3.3.1.4 Autoregressive respiratory effect model (aaddress Kathmandu Valley)

The autoregressive GLM model for Kathmandu Valley residents is as follows.

Table 43: Autoregressive respiratory effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	**β**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	2.285	.2150	1.864	2.707	112.944	1	.000
[Saturday=No]	.411	.0394	.334	.489	109.286	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0010	.0006	0	.002	3.338	1	.068
Temperature_0	.0068	.0031	.001	.013	4.851	1	.028
Relative Humidity_0	-.0070	.0032	-.013	-.001	4.683	1	.030
Rainfall_0	-.0032	.0019	-.007	.001	2.859	1	.091
Respiratory_1	.0061	.0017	.003	.010	12.625	1	.000
Respiratory_2	.0076	.0017	.004	.011	19.247	1	.000
Respiratory_5	.0088	.0017	.005	.012	26.331	1	.000
a. Set to zero because this parameter is redundant.							

Three lag effects at 1, 2 and 5 days of the dependent variable are included as explanatory variables in the model, which reduced autocorrelations significantly. Among the considered predictors, same day effects are found to be statistically significant, which suggests that distributed lag effects are not needed for this respiratory hospitalization response model for Kathmandu residents either. Same day effects of $PM_{2.5}$, temperature, relative humidity and rainfall are found to be statistically significant, with positive correlations for $PM_{2.5}$, temperature, non-Saturdays and lagged variables of respiratory admissions; and negative correlations for relative humidity and rainfall. The coefficients reveal the following relative risks and corresponding percent changes in respiratory admissions per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

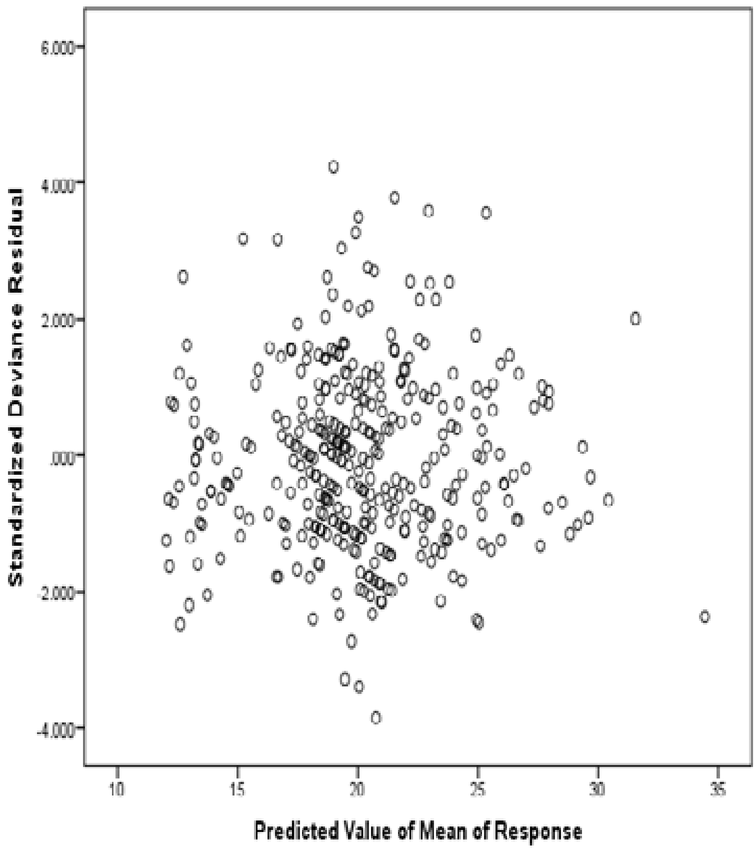
Table 44: Autoregressive respiratory effect model (address Kathmandu Valley): Relative risks

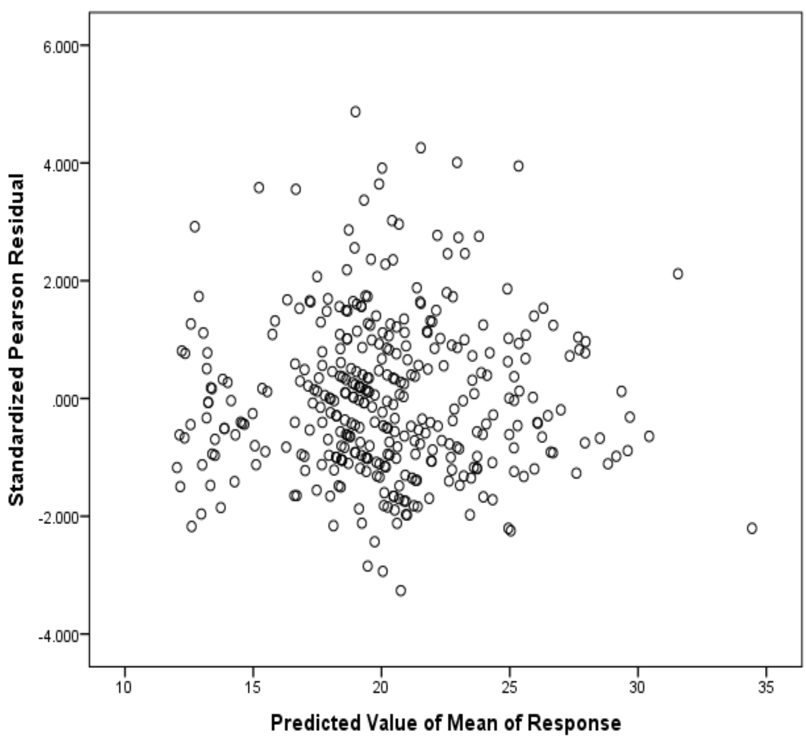
Predictor	Estimate	Difference	Unit	RR	Percent Change
$PM_{2.5}$_0	0.001	10	µg/m^3	1.010	1.01
Temperature_0	0.0068	1	^{0} Celsius	1.007	0.68
Relative Humidity_0	-0.007	1	%	0.993	-0.70
Rainfall_0	-0.0032	1	mm	0.997	-0.32
Non-Saturdays*	0.411	1	-	1.508	50.83
*Categorical variable					

Autoregressive respiratory effect model (address Kathmandu Valley): Model adequacy tests

Table 45: Autoregressive respiratory effect model (address Kathmandu Valley): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=863.2 at 359 df; Residual Deviance:605 at 351 df Omnibus test: highly significant with log likelihood chi-square: (258.2 at 8 df; p <0.0001)	Good
Multicollinearity	VIFs <2.6	No multicollinearity
Heteroscedasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Absence of significant autocorrelations
Normality	KS test for deviance residual with p = 0.24; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
10
15
20
25
30
35
Predicted Value of Mean of Response


6.000
4.000
2.000
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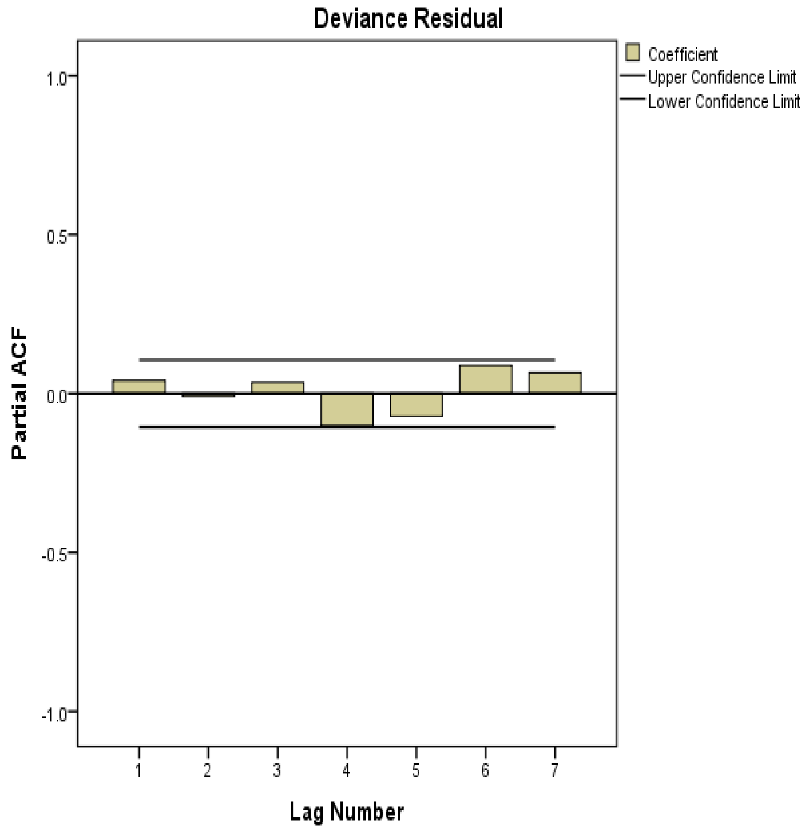
-2.000
-4.000
Standardized Pearson Residual
10
15
20
25
30
35
Predicted Value of Mean of Response


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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0.5
0.0
-0.5
-1.0
1
2
3
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5
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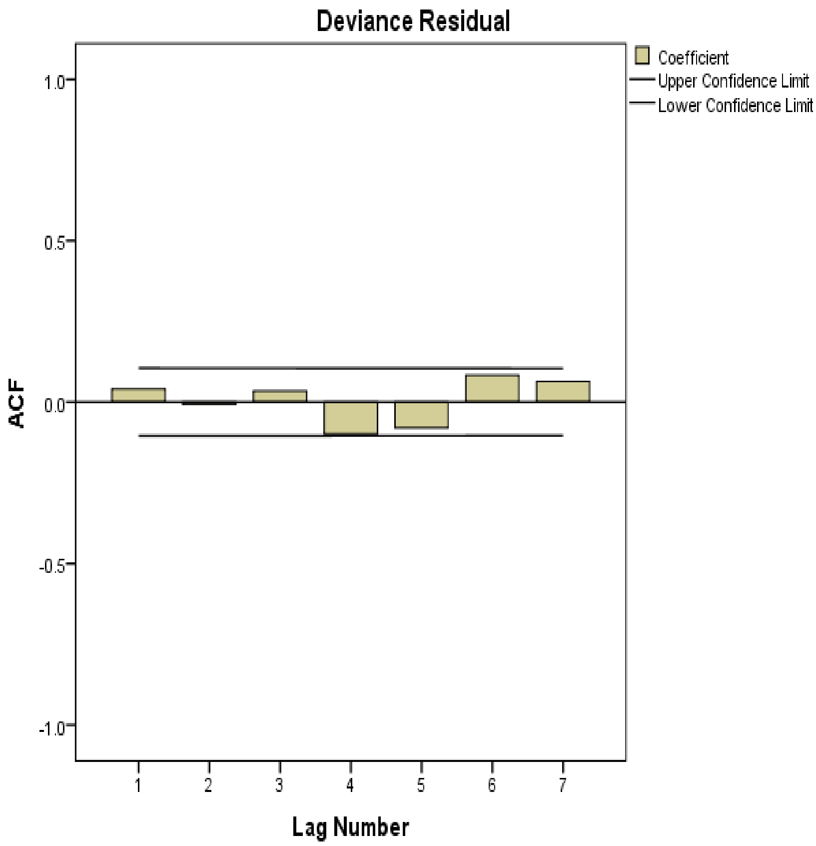
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
1.0
0.5
0.0
-0.5
-1.0
1
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Lag Number

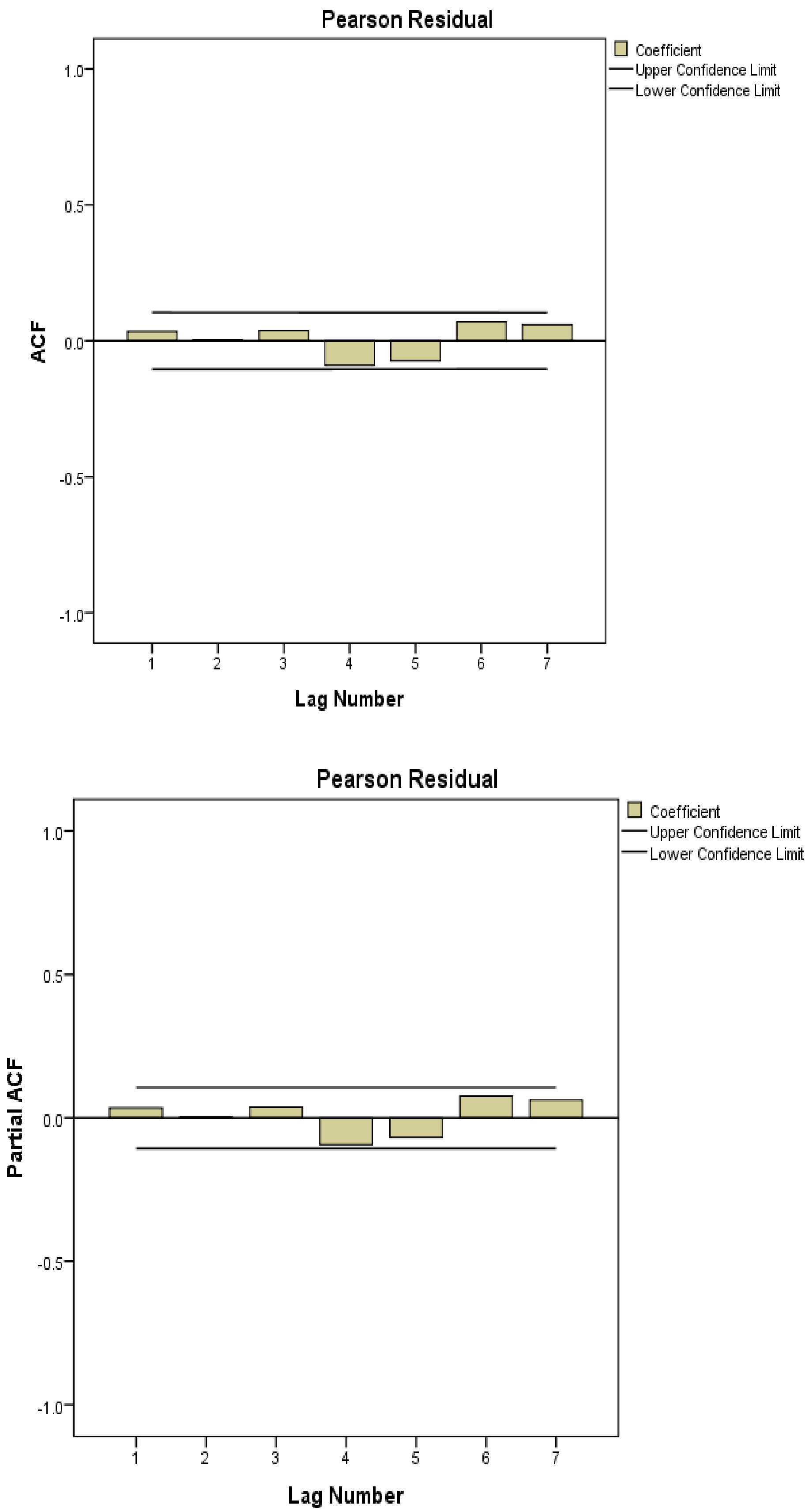


Figure 38: Autoregressive respiratory effect model (address Kathmandu Valley): Model adequacy tests

3.3.1.5 Comparative assessment between respiratory effect GLMs

Table 46: Comparative assessment between respiratory effect GLMs

Particular	Respiratory		Respiratory (Autoregressive)		Respiratory KTM		Respiratory KTM (Autoregressive)	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	1.014 (0.001)	0	1.01 (0.04)	0	1.41 (0.007)	0	1.01 (0.068)	0
CO	X		X		X		X	
NO_2	X		X		X		X	
Temperature	1.01 (0.000)	0	0.64 (0.01)	0	1.03 (0.001)	0	0.68 (0.03)	0
Relative Humidity	-1.28 (0.03)	0	-0.58 (0.03)	0	-1.61 (0.000)	0	-0.70 (0.03)	0
Rainfall	-0.34 (0.023)	0	-0.34 (0.025)	0	-0.35 (0.065)	0	-0.32 (0.09)	0
Non-Saturday	44.2 (0.000)	-	42.8 (0.000)	-	44.8 (0.000)	-	50.8 (0.000)	
Autoregressive Lag effects	-	-		1, 2, 7 (+)	-	-		1, 2, 5 (+)

Interpretation / Assessment

Comparing the percent change in respiratory hospital admissions per 10 µg/m^3 rise in $PM_{2.5}$, it is observed that the change is slightly higher (1.41%) for Kathmandu resident inpatients compared to all inpatients (1.014%). Moreover, autoregressive models show around 1% rise in respiratory hospitalizations per 10 µg/m^3 rise in $PM_{2.5}$. CO and NO_2 are found to be statistically insignificant for all four developed respiratory effect models. Temperature effect is lower in autocorrelation-corrected models (around 0.65% increase in respiratory morbidity per 1^0 Celsius increase in temperature) compared to around 1% in uncorrected models. Also, a similar percentage increase (1%) is seen for both the all addresses model and the Kathmandu address model. Rainfall is associated with around 0.33% decrease in respiratory hospitalizations per 1 mm increase in rainfall. Relative humidity is also associated with 0.6-1.6% decrease in respiratory hospitalizations per 1% increase in relative humidity. The risk of hospitalization is greater on working days compared to holidays (Saturdays) as shown by all four developed respiratory effect models, with around 40-50% increase in hospitalizations for non-Saturdays. Slight autocorrelations are observed for the models considered for respiratory hospitalization at 1, 2, 5 and 7 day lags, which are corrected for in the autoregressive GLMs.

3.3.2 COPD effect models

The COPD effect model has COPD hospitalizations as the response variable. The models with and without autocorrelation-corrected lagged terms are presented below. In total, four models were developed with COPD hospitalizations as the response variable.

3.3.2.1 COPD effect model (all addresses inclusive)

The model is as follows.

Table 47: COPD effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.462	.1554	3.157	3.766	496.004	1	.000
[Saturday=No]	.424	.0504	.325	.523	70.677	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$ _0	.0014	.0005	.000	.002	7.155	1	.007
Relative Humidity_0	-.0328	.0034	-.039	-.026	94.463	1	.000
Rainfall_0	-.0071	.0026	-.012	-.002	7.645	1	.006
NO_2_2 (mean)	.1147	.0641	-.011	.240	3.206	1	.073
a. Set to zero because this parameter is redundant.							

Among the considered predictors, same day effects are found to be statistically significant (p<0.05) for $PM_{2.5}$ and meteorological parameters, but a two day mean effect (same and 1 day before) was detected for NO_2. Same day effects of $PM_{2.5}$, relative humidity and rainfall, and two day mean effect of NO_2 are found to be statistically significant with positive correlations for $PM_{2.5}$, NO_2, temperature, non-Saturdays; and negative correlations for relative humidity and rainfall. The coefficients reveal the following relative risks and corresponding percent changes in COPD admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

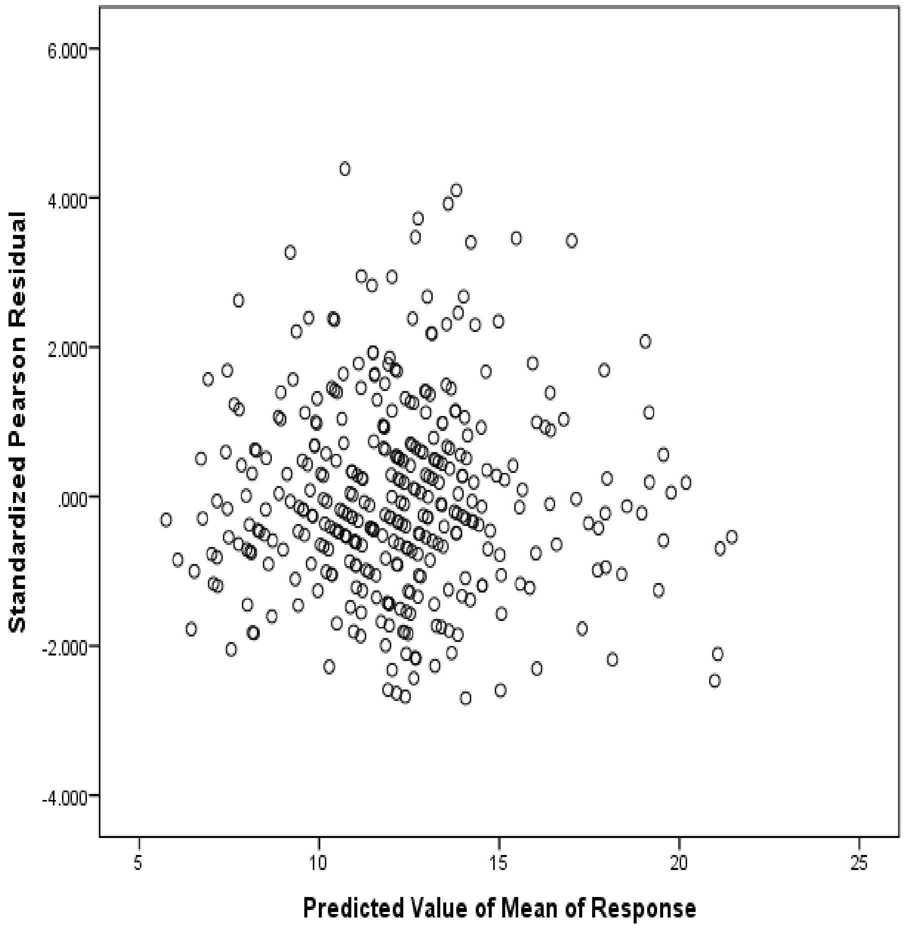
Table 48: COPD effect model (all addresses inclusive): Relative risks

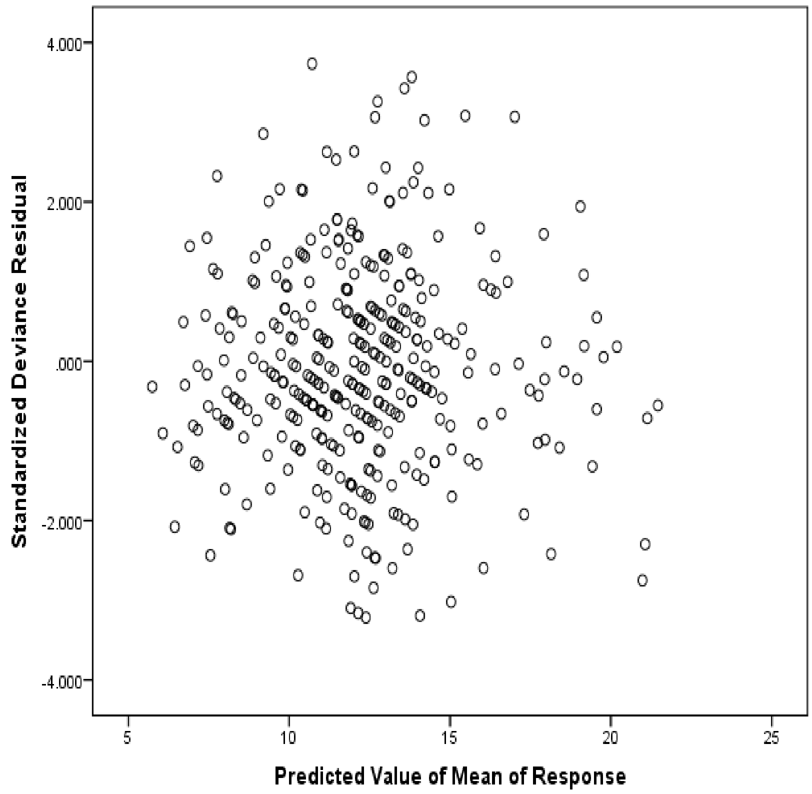
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0014	10	μg/m³	1.014	1.41
NO_2 _2 (mean)	0.1147	1	mg/m³	1.122	12.15
Relative Humidity_0	-0.0328	1	%	0.968	-3.23
Rainfall_0	-0.0071	1	mm	0.993	-0.71
Non-Saturdays*	0.424	1	-	1.528	52.81
*Categorical variable					

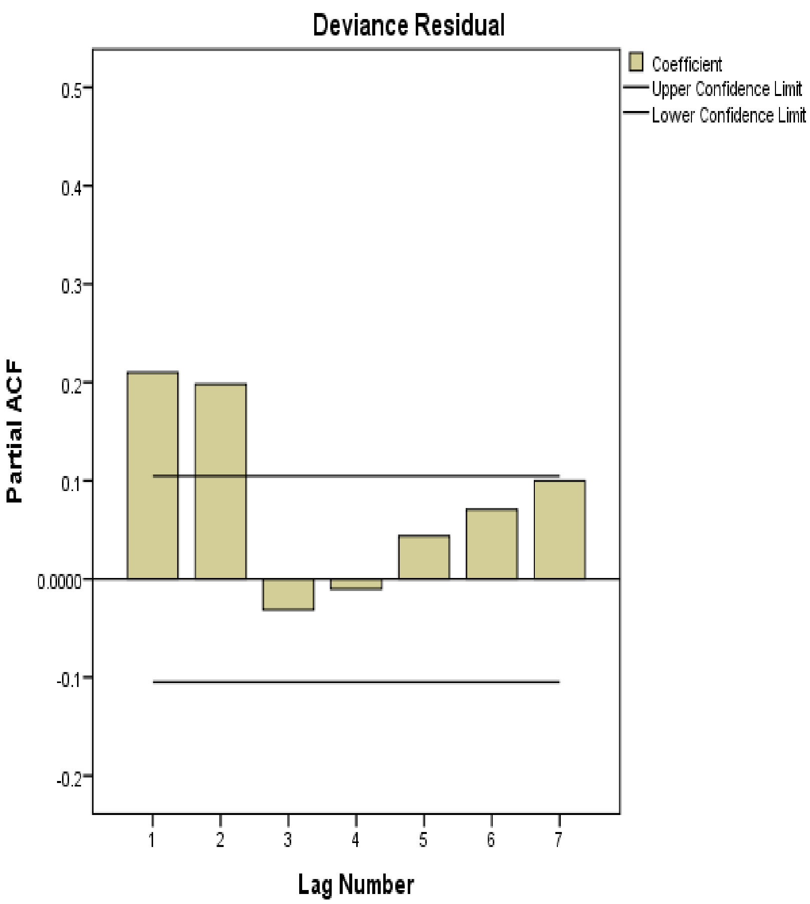
COPD effect model (all addresses inclusive): Model adequacy tests

Table 49: COPD effect model (all addresses inclusive): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=844.1 at 363 df; Residual Deviance:605.6 at 358 df Omnibus test: highly significant with log likelihood chi-square: (238.6 at 5 df; p <0.0001)	Good
Multicollinearity	VIFs <1.4	No multicollinearity
Heteroscedasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations at 1 and 2 lags
Normality	KS test for deviance residual with p = 0.61; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected




4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
5
10
15
20
25
Predicted Value of Mean of Response


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
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0.4
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0.2
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Partial ACF
1
2
3
4
5
6
7
Lag Number

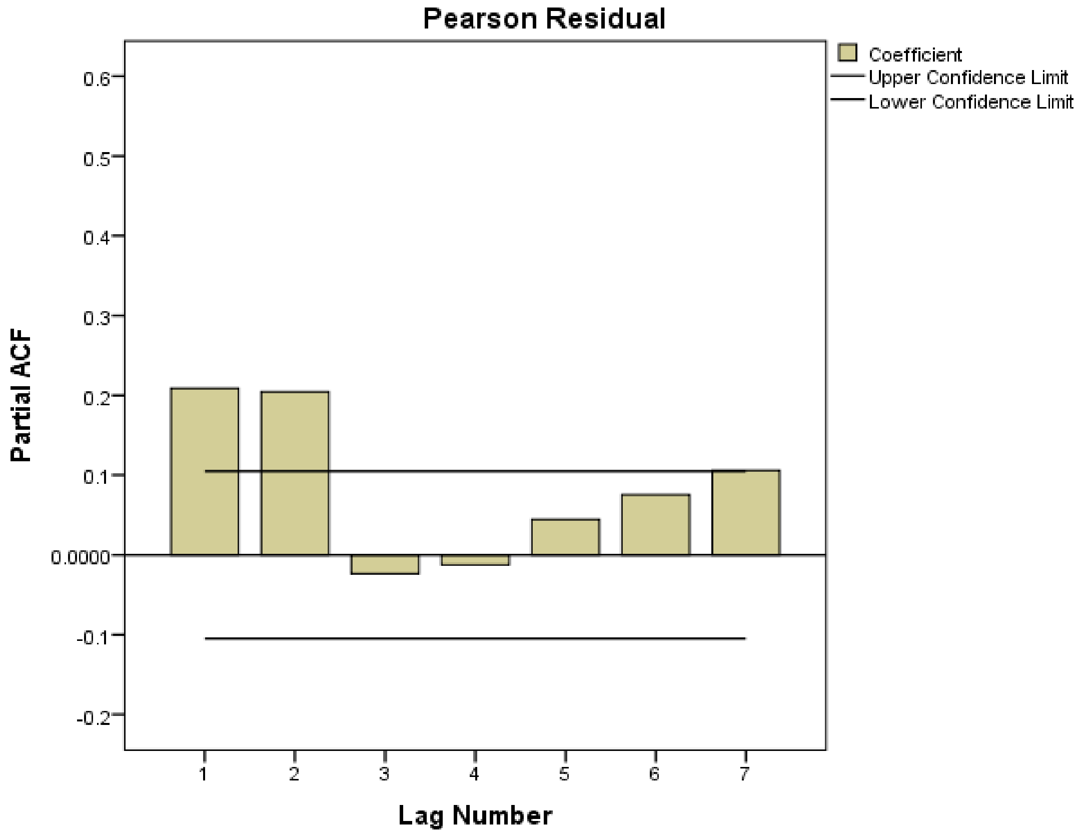


Figure 39: COPD effect model (all addresses inclusive): Model adequacy tests

3.3.2.2 Autoregressive COPD effect model (all addresses inclusive)

The autoregressive GLM model with COPD hospitalizations as the response variable is presented below.

Table 50: Autoregressive COPD effect model (all addresses inclusive)

Parameter Estimates							
Parameter	**β**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	2.549	.1998	2.157	2.940	162.668	1	.000
[Saturday=No]	.436	.0505	.337	.535	74.574	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0010	.0005	-9.590E-005	.002	3.174	1	.075
Relative Humidity_0	-.0197	.0038	-.027	-.012	26.260	1	.000
Rainfall_0	-.0054	.0026	-.010	.000	4.384	1	.036
NO_2_2 (mean)	.0859	.0641	-.040	.211	1.797	1	.180
COPD_1	.0115	.0030	.006	.017	14.327	1	.000
COPD_2	.0172	.0030	.011	.023	32.100	1	.000
a. Set to zero because this parameter is redundant.							

Addition of lag effects of the dependent variable in the model produced insignificant autocorrelations and slight changes in model coefficients (signs remain the same), and a similar degree of statistical significance to the model without autoregressive terms. The corrected coefficients reveal the following relative risks and corresponding percent changes in COPD admission per unit (as indicated) increase in predictor values (or codes). Even though NO_2 is found to be statistically insignificant it is retained to examine its impact on the dependent variable. Relative risks and percent increases are given below.

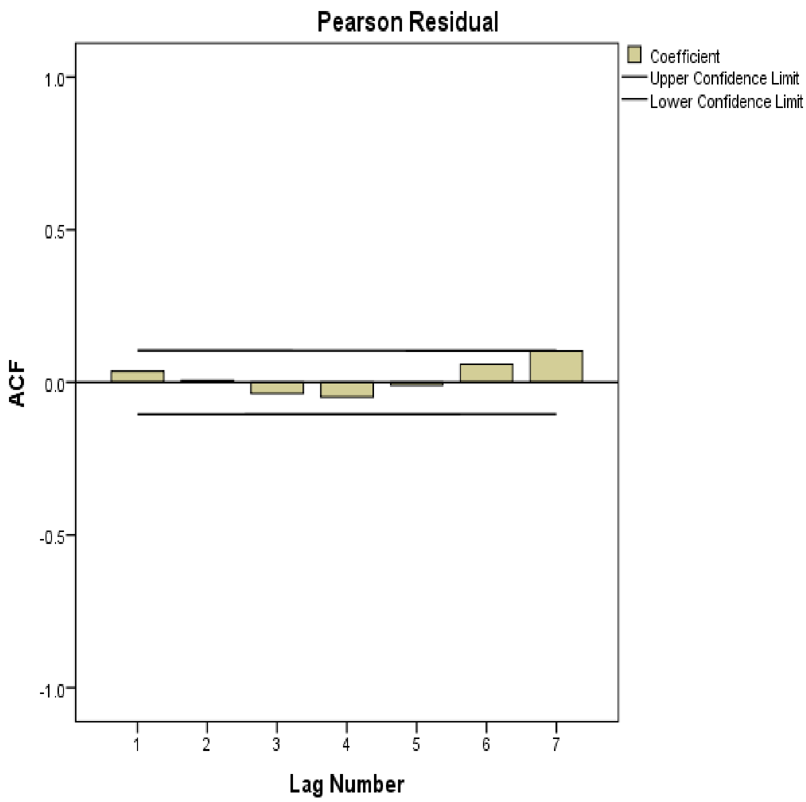
Table 51: Autoregressive COPD effect model (all addresses inclusive): Relative risks

Predictor	Estimate	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.001	10	µg/m³	1.010	1.01
NO_2 _2 (mean)	0.0859	1	mg/m³	1.090	8.97
Relative Humidity_0	-0.0197	1	%	0.980	-1.95
Rainfall_0	-0.0054	1	mm	0.995	-0.54
Non-Saturdays*	0.436	1	-	1.547	54.65
*Categorical variable					

Autoregressive COPD effect model (all addresses inclusive): Model adequacy tests

Table 52: Autoregressive COPD effect model (all addresses inclusive): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=843.1 at 362 df; Residual Deviance:550 at 356 df Omnibus test: highly significant with log likelihood chi-square: (291.1 at 6 df; p <0.0001)	Good
Multicollinearity	VIFs <1.5	No multicollinearity
Heteroscedasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No autocorrelations
Normality	KS test for deviance residual with p = 0.86; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
1.0
0.5
0.0
-0.5
-1.0
1
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3
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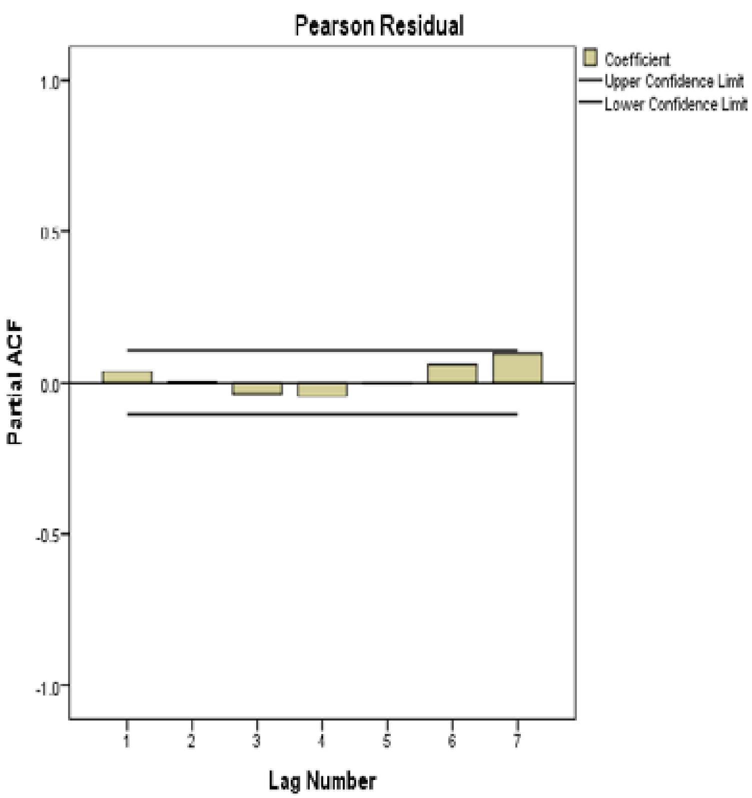
Lag Number


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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0.5
0.0
-0.5
-1.0
1
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3
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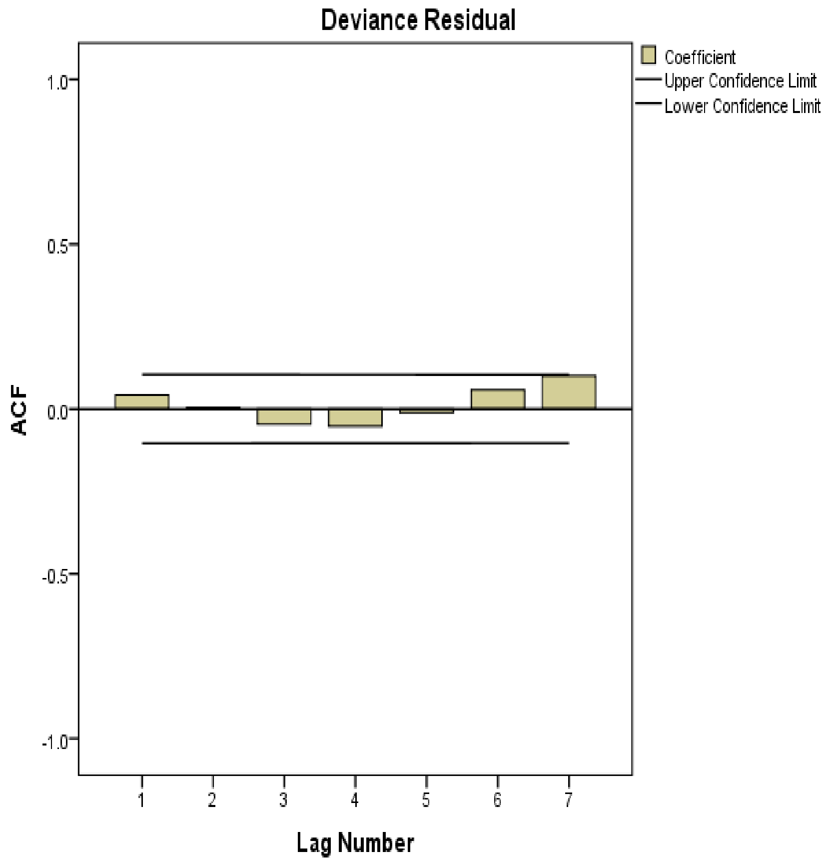
5
6
7
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
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ACF
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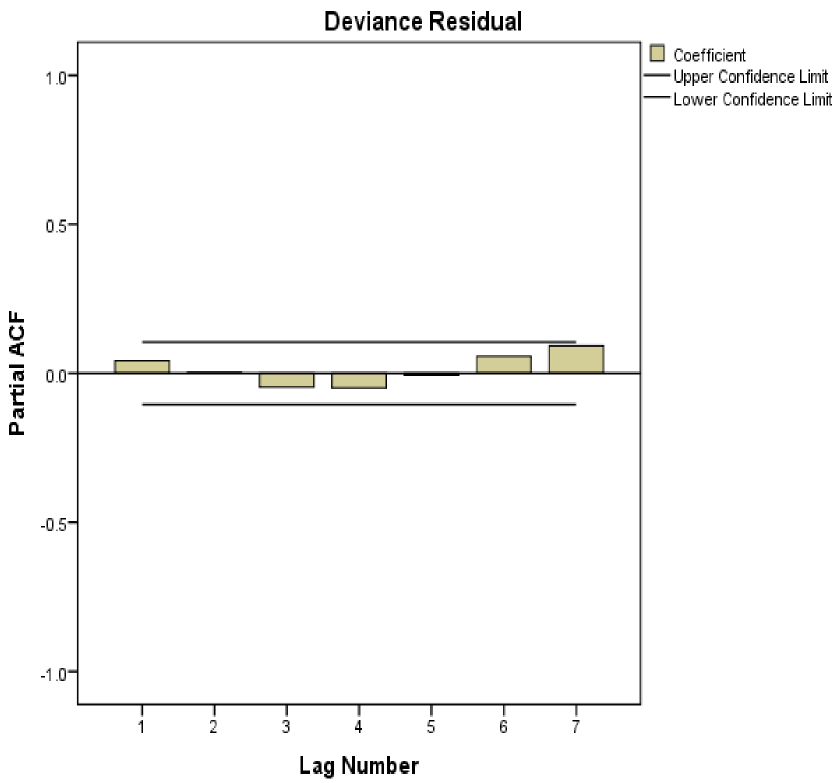
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
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Partial ACF
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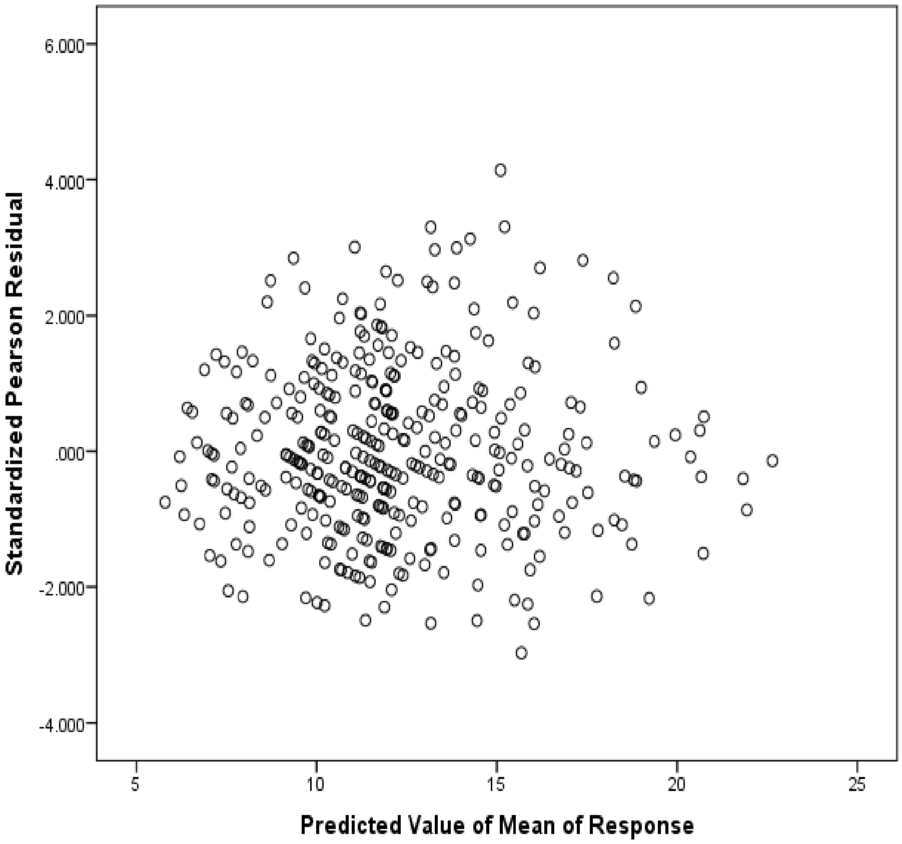
7
Lag Number



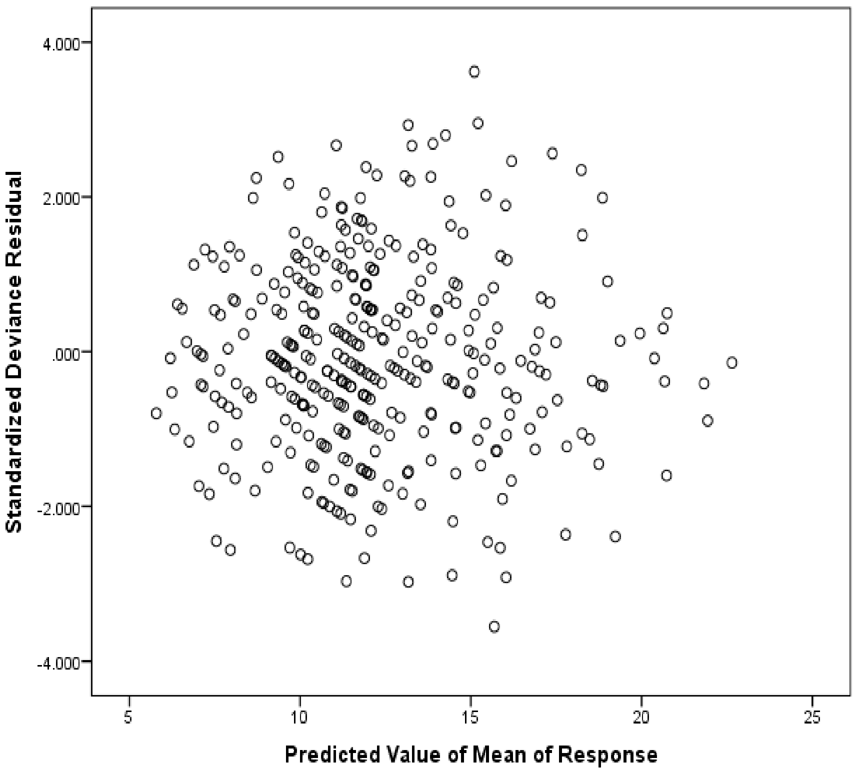


Figure 40: Autoregressive COPD effect model (all addresses inclusive): Model adequacy tests

3.3.2.3 COPD effect model (address Kathmandu Valley)

Table 53: COPD effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.170	.1941	2.790	3.551	266.760	1	.000
[Saturday=No]	.398	.0621	.277	.520	41.111	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
Relative Humidity_0	-.0367	.0042	-.045	-.029	78.039	1	.000
$PM_{2.5}$ _0	.0016	.0007	.000	.003	4.947	1	.026
NO_2_7 (mean)	.2706	.1398	-.003	.545	3.748	1	.053
a. Set to zero because this parameter is redundant.							

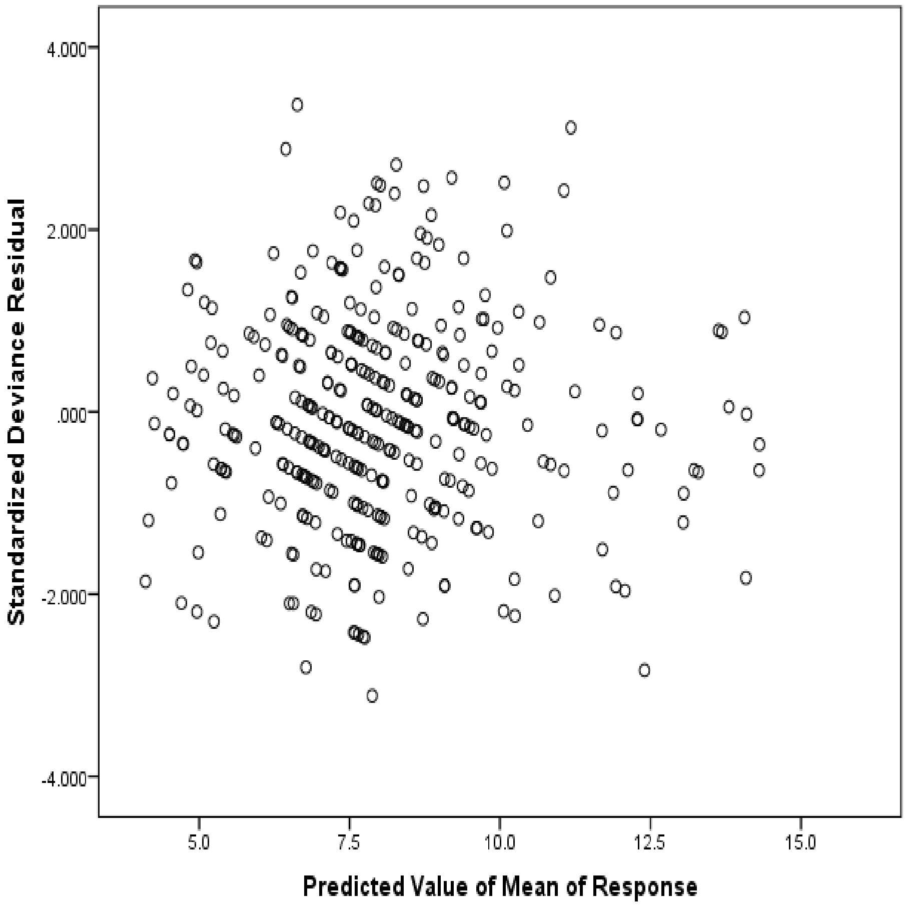
The COPD response model for inpatients with Kathmandu Valley address shows that $PM_{2.5}$ and relative humidity have same day effects on COPD admission, while NO_2 has a week mean effect. Positive correlations are found for $PM_{2.5}$, NO_2 and non-Saturdays; and negative correlations for relative humidity. The coefficients reveal the following relative risks and corresponding percent changes in COPD admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increase are given below.

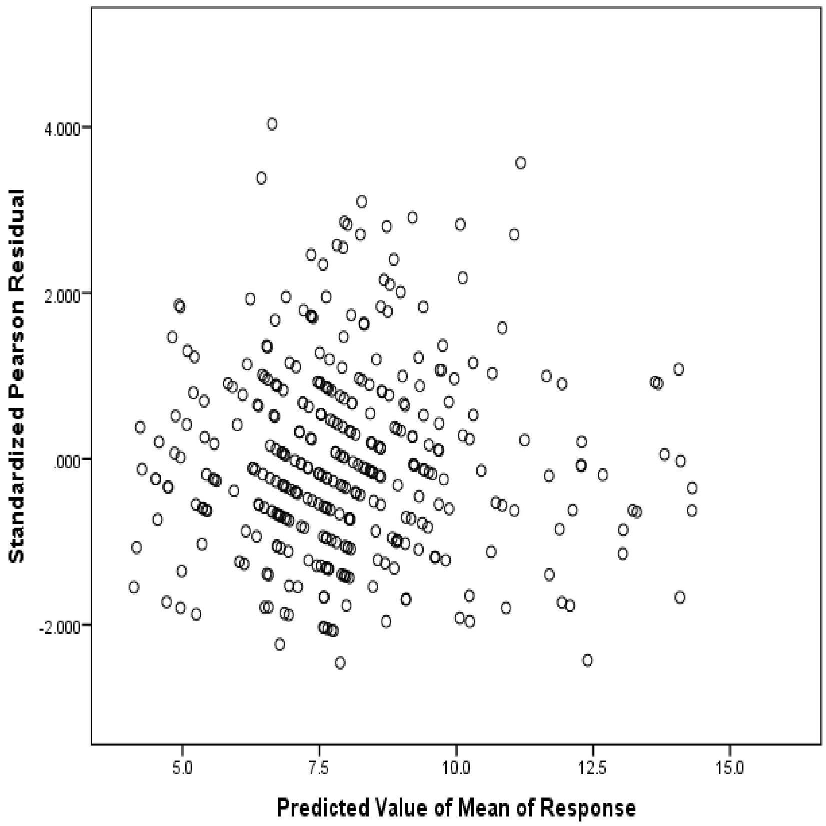
Table 54: COPD effect model (address Kathmandu Valley): Relative risks

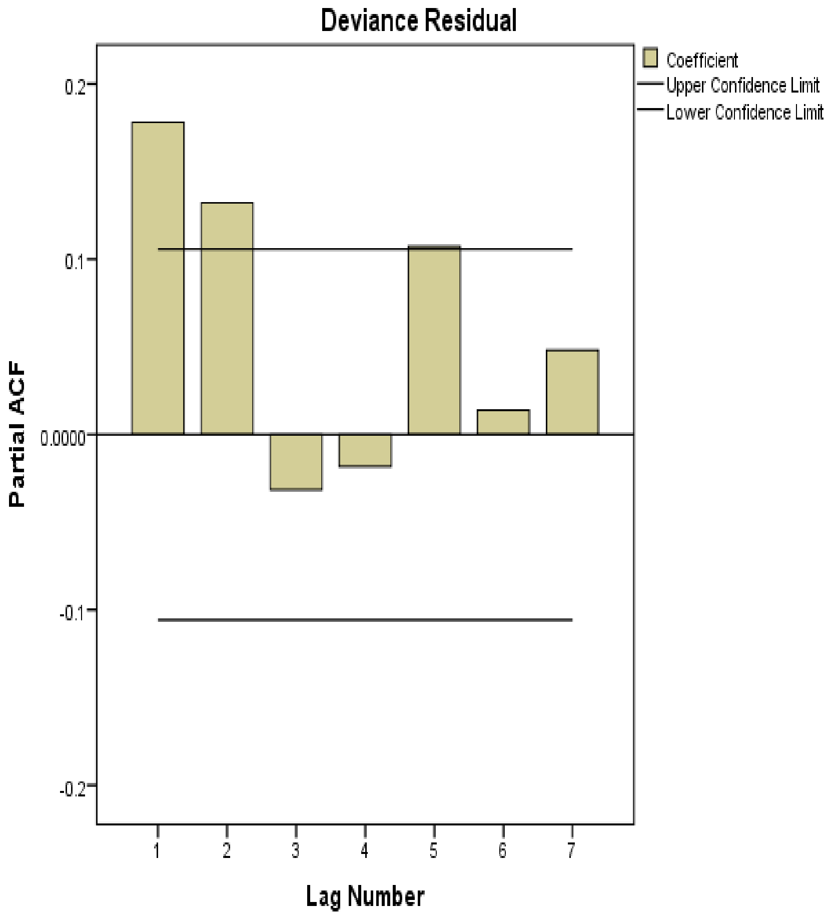
Predictor	Estimate	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0016	10	µg/m³	1.020	2.02
NO_2 _7 (mean)	0.2706	1	mg/m³	1.311	31.13
Relative Humidity_0	-0.0367	1	%	0.964	-3.63
Non-Saturdays*	0.398	1	-	1.489	48.88
*Categorical variable					

Table 55: COPD effect model (address Kathmandu valley): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=645 at 387 df; Residual Deviance:481.2 at 353 df Omnibus test: highly significant with log likelihood chi-square: (163.8 at 4 df; p <0.0001)	Good
Multicollinearity	VIFs <1.6	No multicollinearity
Heteroscedasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations at 1, 2 and 5 lags
Normality	KS test for deviance residual with p = 0.72; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected




4.000
2.000
.000
-2.000
Standardized Pearson Residual
5.0
7.5
10.0
12.5
15.0
Predicted Value of Mean of Response


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.2
0.1
0.0000
-0.1
-0.2
Partial ACF
1
2
3
4
5
6
7
Lag Number

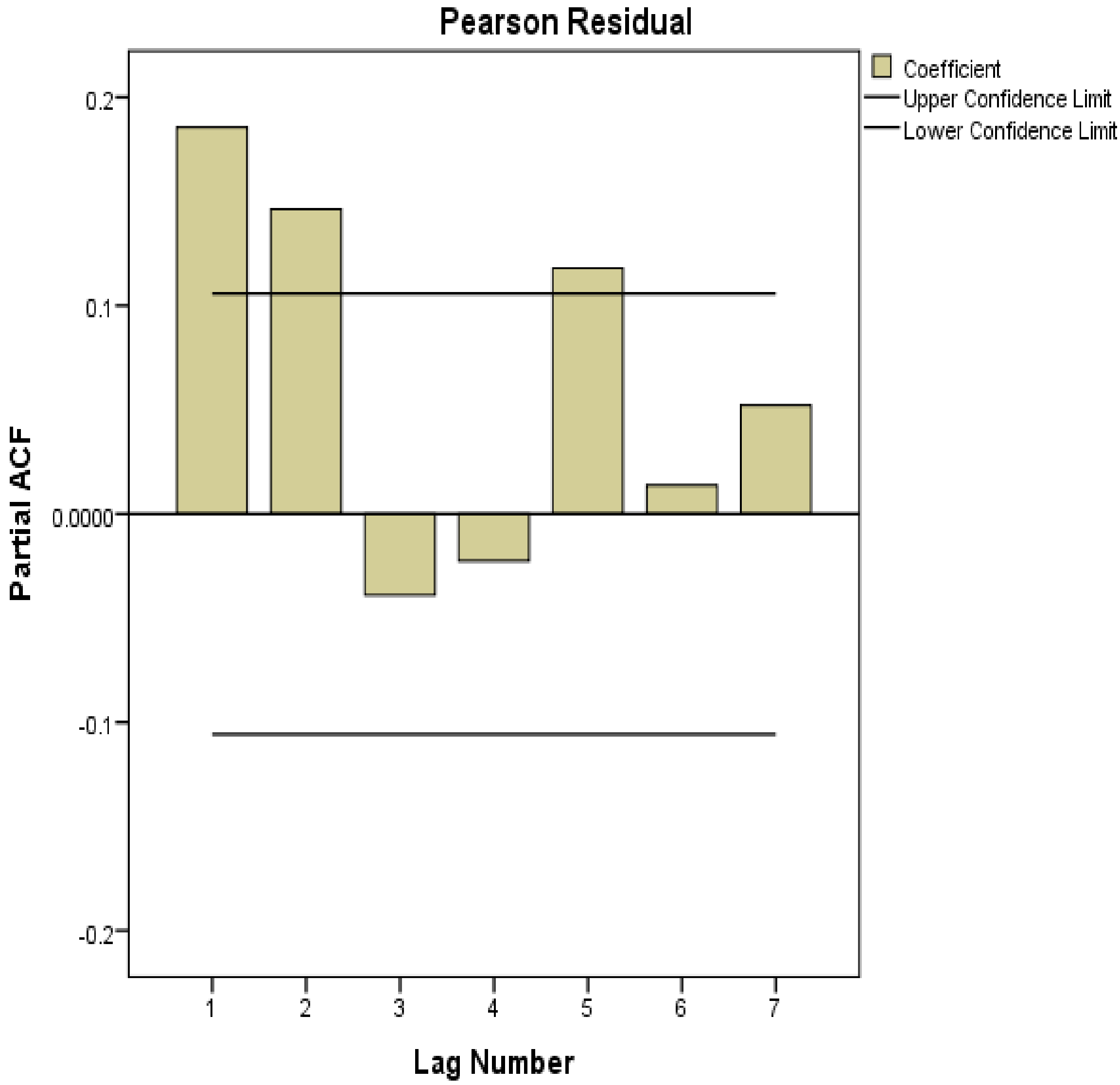


Figure 41: COPD effect model (address Kathmandu Valley): Model adequacy tests

3.3.2.4 Autoregressive COPD effect model (address Kathmandu Valley)

The autoregressive GLM for inpatients with addresses in Kathmandu Valley is presented below.

Table 56: Autoregressive COPD effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	2.515	.2460	2.033	2.998	104.535	1	.000
[Saturday=0]	.391	.0622	.269	.513	39.496	1	.000
[Saturday=1]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0013	.0007	0	.003	3.348	1	.067
Relative Humidity_0	-.0266	.0048	-.036	-.017	31.095	1	.000
NO_2_7 (mean)	.2321	.1412	-.045	.509	2.703	1	.100
COPD_1	.0120	.0053	.002	.022	5.220	1	.022
COPD_2	.0181	.0053	.008	.028	11.895	1	.001
a. Set to zero because this parameter is redundant.							

Two autoregressive terms were added at 1 and 2 day lag for autocorrelation reduction. Slight changes in coefficient values are detected with this autoregressive model compared to the model without autoregressive terms. The model for inpatients with Kathmandu Valley addresses shows that $PM_{2.5}$ and relative humidity have same day effects on COPD admission; while NO_2 has a one week mean effect. The coefficients reveal the following relative risks and corresponding percent changes in COPD admission per unit (as indicated) increase in predictor values (or codes). Relative Risks and Percent increase are given below.

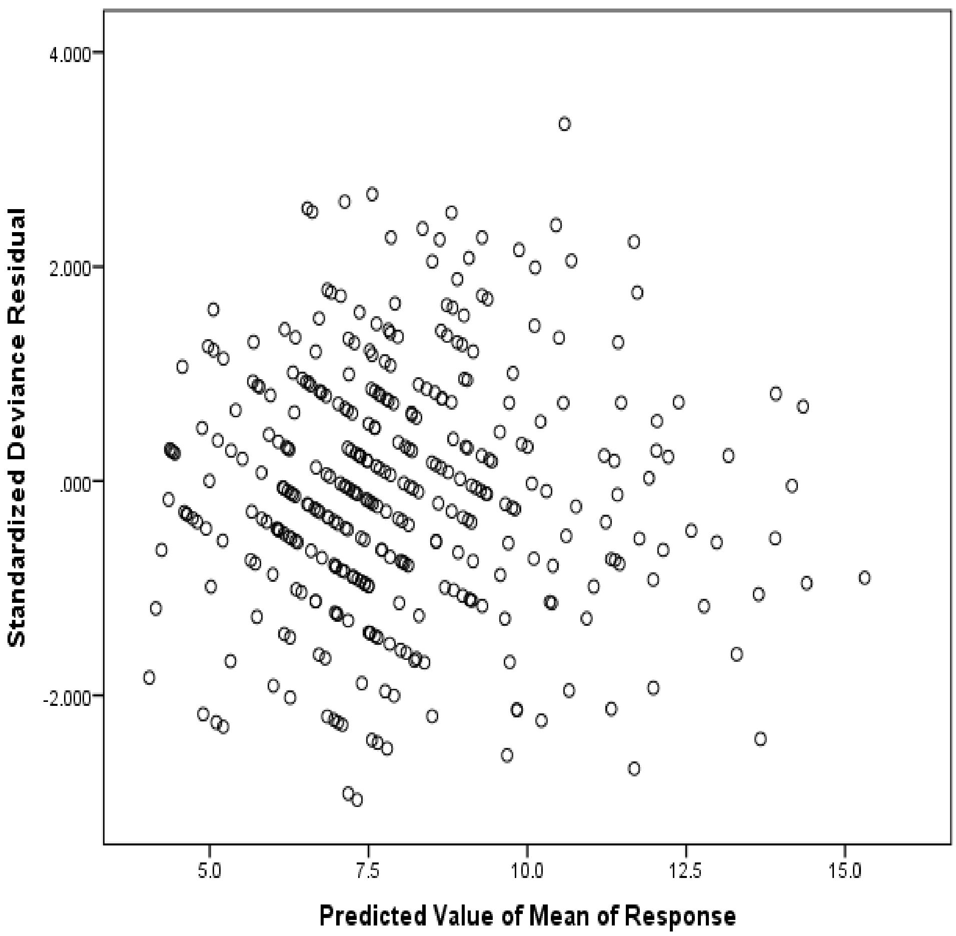
Table 57: Autoregressive COPD effect model (address Kathmandu Valley): Relative risks

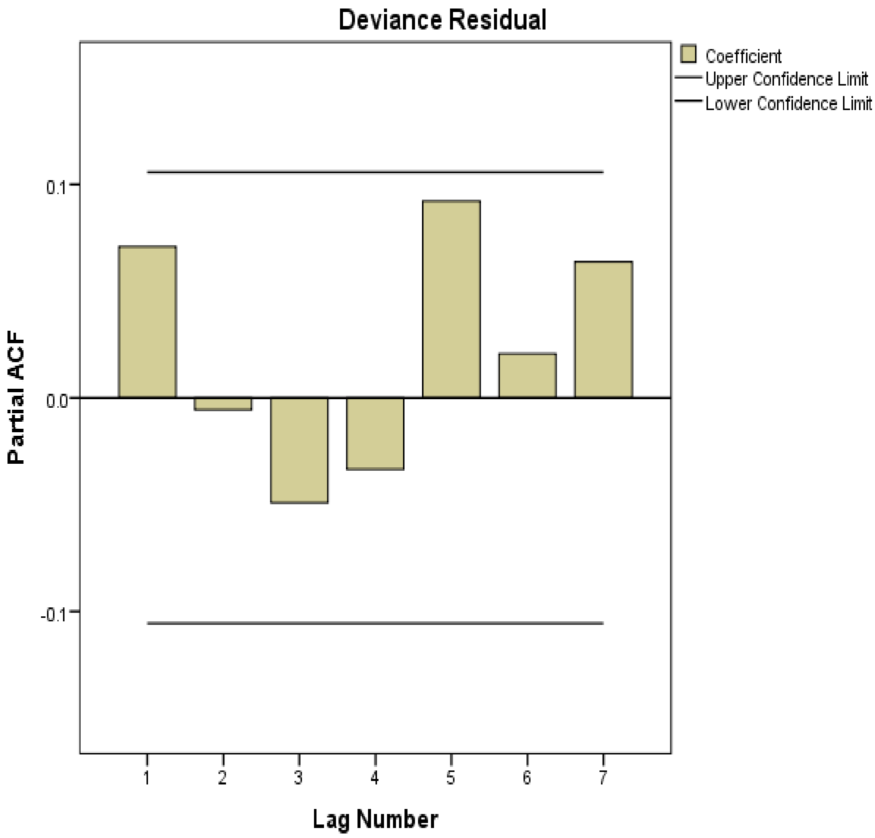
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0013	10	$\mu g/m^3$	1.013	1.31
NO_2 _7 (mean)	0.2321	1	mg/m^3	1.261	26.12
Relative Humidity_0	-0.0266	1	%	0.974	-2.62
Non-Saturdays*	0.391	1	-	1.478	47.85
*Categorical variable					

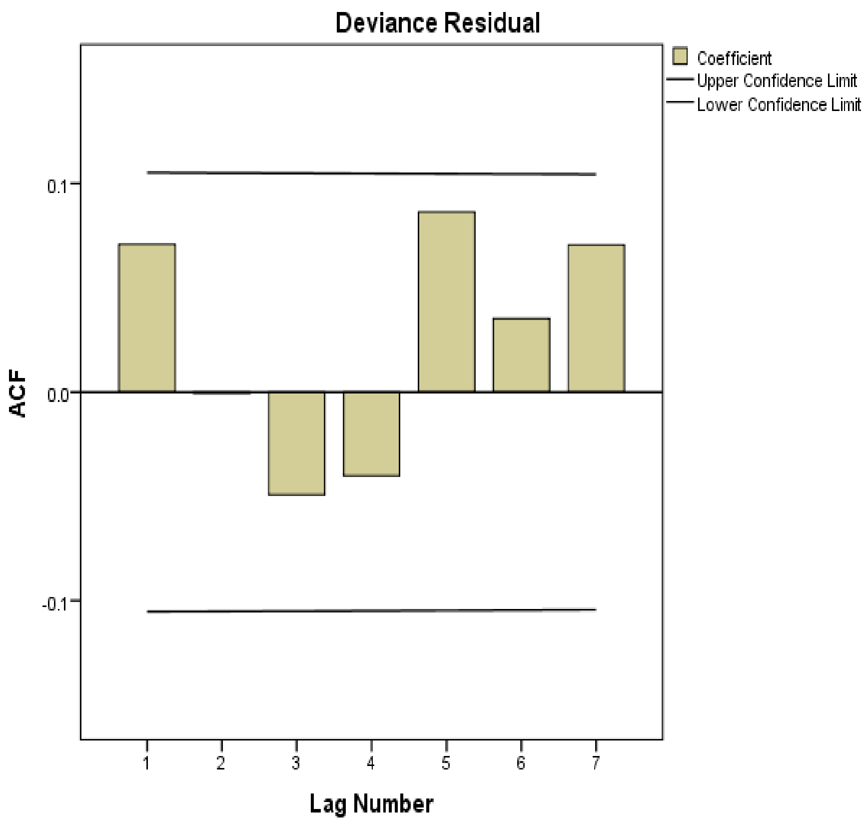
Autoregressive COPD effect model (address Kathmandu Valley): Model adequacy tests

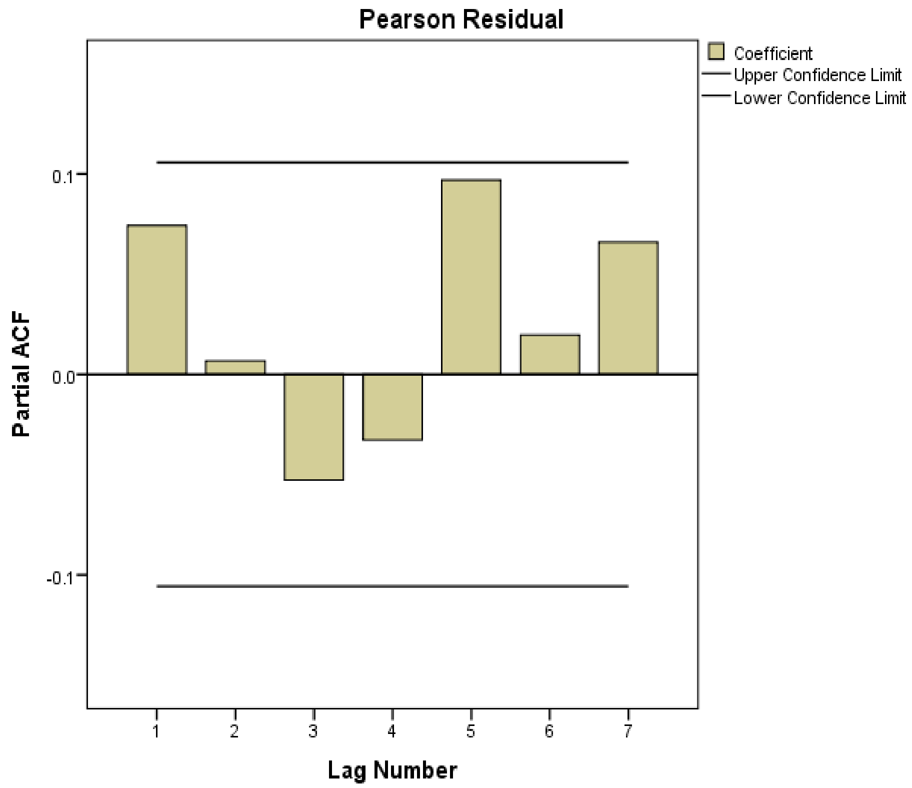
Table 58: Autoregressive COPD effect model (address Kathmandu Valley): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=645 at 357 df; Residual Deviance:461.8 at 351 df Omnibus test: highly significant with log likelihood chi-square: (183.6 at 6 df; p <0.0001)	Good
Multicollinearity	VIFs <1.6	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p = 0.56; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected




Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number



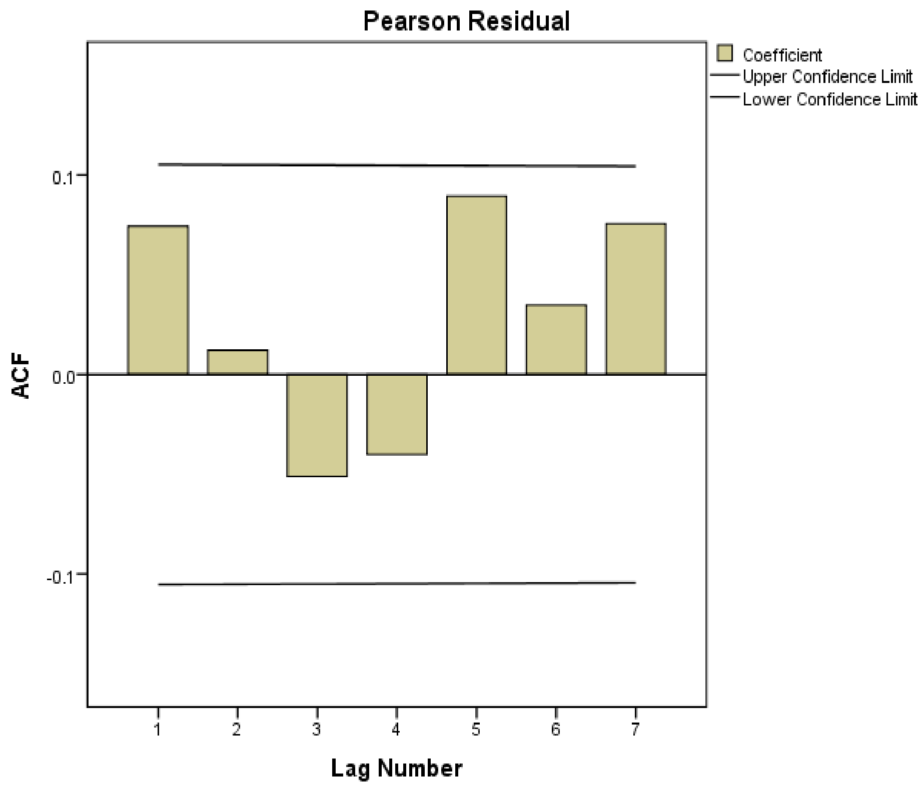


Figure 42: Autoregressive COPD effect model (address Kathmandu Valley): Model adequacy tests

3.3.2.5 Comparative assessment between COPD effect GLMs

Table 59: Comparative assessment between COPD effect GLMs

Particular	COPD		COPD (Autoregressive)		COPD KTM		COPD KTM (Autoregressive)	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	1.41 (0.01)	0	1.01 (0.07)	0	2.02 (0.03)	0	1.31 (0.07)	0
CO	X		X		X		X	
NO_2	12.15 (0.07)	2 day mean	8.97 (0.18)	2 day mean	31.13 (0.05)	7 day mean	26.12 (0.10)	7 day mean
Temperature	X		X		X		X	
Relative Humidity	-3.23 (0.00)	0	-1.95 (0.00)	0	-3.63 (0.00)	0	-2.62 (0.00)	0
Rainfall	-0.71 (0.01)	0	-0.54 (0.04)	0	X		X	
Non-Saturday	52.8 (0.00)	-	54.6 (0.00)	-	48.9 (0.00)	-	47.9 (0.00)	
Autoregressive Lag effects	-	-		1, 2 (+)	-	-		1, 2 (+)

Interpretation / Assessment

When considering the percentage change in COPD hospital admissions per 10 μg/m^3 rise in $PM_{2.5}$, it is observed that the change is higher (2%) for Kathmandu resident inpatients than for all inpatients (1.4%). However, autoregressive models show only around 1-1.3% rise in COPD hospitalizations per 10 μg/m^3 rise in $PM_{2.5}$, which is lower than the autocorrelation uncorrected models. Two and seven day positive lag effects are detected for NO_2, with high variability in effects between models. Comparatively speaking, effects of NO_2 are higher (using the 7 day mean effect) for inpatients with Kathmandu addresses (26-31%) compared to 9-12% for all addresses inclusive. CO and temperature are found to be statistically insignificant for all four developed COPD effect models. A protective relative humidity effect exists and offers a similar (3.2% versus 3.6%) decrease in COPD admission per 1% rise in relative humidity for both the all-addresses model and Kathmandu addresses model. Rainfall is also negatively associated with around 0.7% decrease in COPD hospitalization per 1% increase in relative humidity for the all-addresses models and around 0.5% decrease for Kathmandu addresses models. The risk of hospitalization is greater on working days than holidays (i.e. Saturday) in all four developed COPD effect models, with around 48-55% increase in hospitalizations for non-Saturdays. Slight autocorrelations are observed for the models considered for COPD hospitalizations at 1 and 2 day lags, which can be corrected for as shown by the autoregressive GLMs.

3.3.3 ARI effect models

The models with ARI as the response variable are presented below.

3.3.3.1 ARI effect model (all addresses inclusive)

The model with ARI response is given below.

Table 60: ARI effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.982	.1406	1.706	2.257	198.731	1	.000
[Saturday=No]	.319	.0453	.230	.408	49.583	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_7 (Geo)	.0027	.0009	.001	.004	9.434	1	.002
CO_7 (AM)	-.1232	.0517	-.225	-.022	5.674	1	.017
NO2_7 (AM)	-.3535	.1210	-.591	-.116	8.541	1	.003
Temperature_7 (mean)	.0182	.0041	.010	.026	19.662	1	.000
Rainfall_7 (mean)	-.0127	.0040	-.020	-.005	10.302	1	.001
a. Set to zero because this parameter is redundant.							

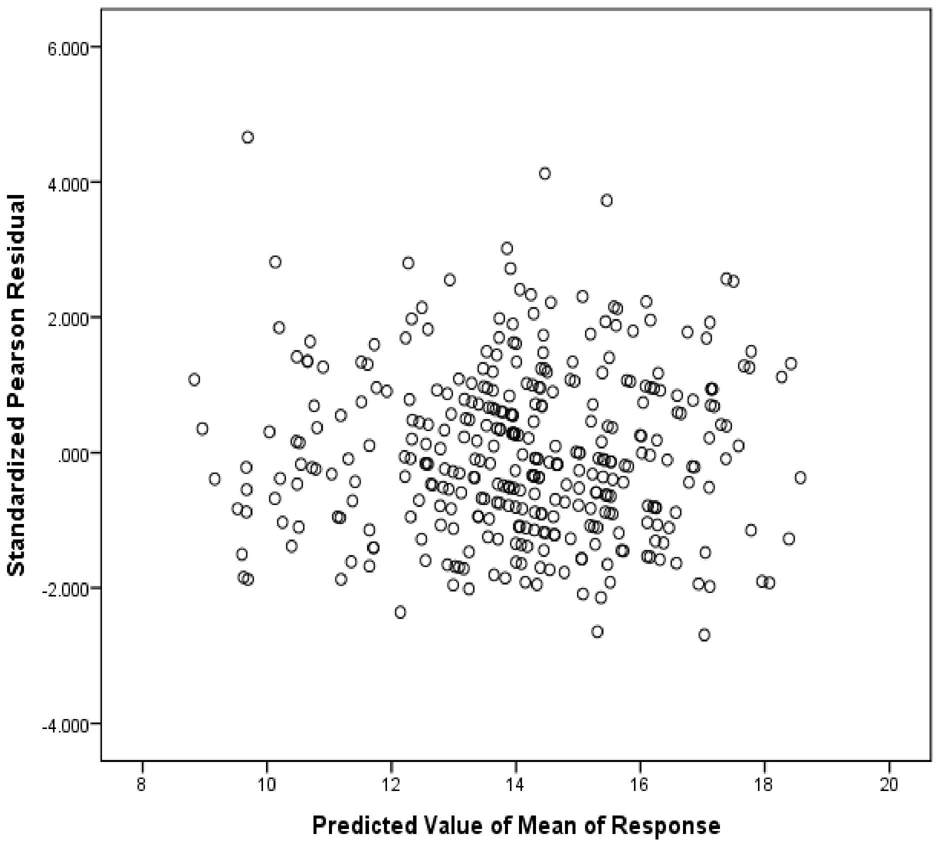
The ARI effect model shows distributed lag effects of various predictors. $PM_{2.5}$ showed a positive 7 day geometric lag effect while CO and NO_2 showed negative 7 day arithmetic lag effects. Temperature (positive) and relative humidity (negative) showed 7 day mean effects on ARI. The coefficients reveal the following relative risks and corresponding percent changes in ARI admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

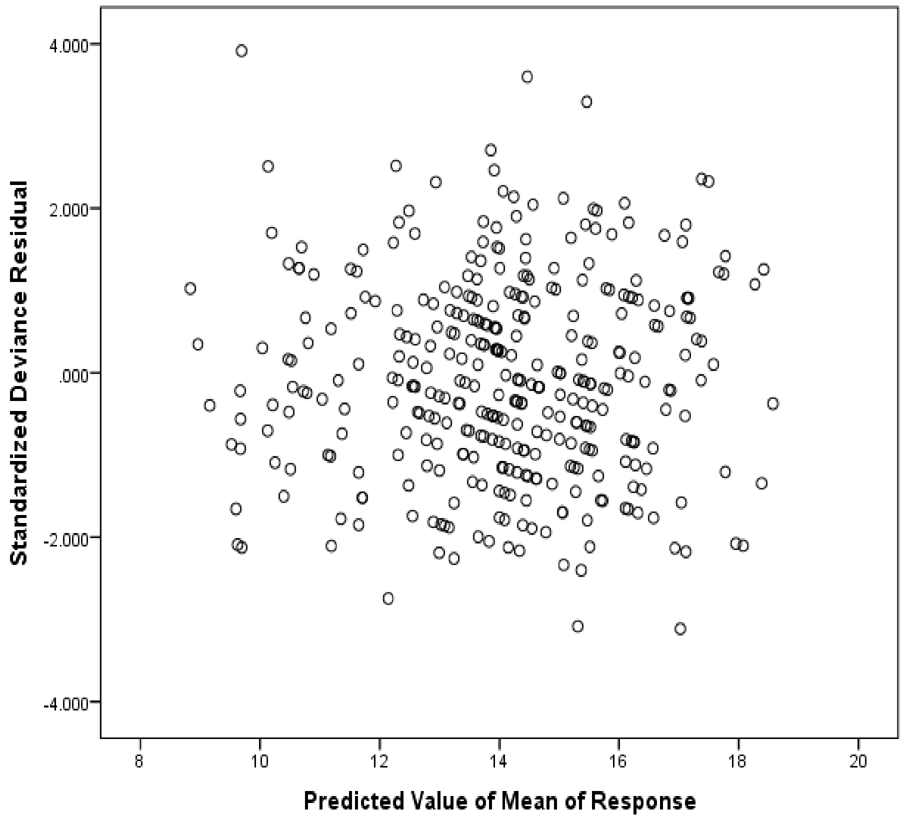
Table 61: ARI effect model (all addresses inclusive): Relative risks

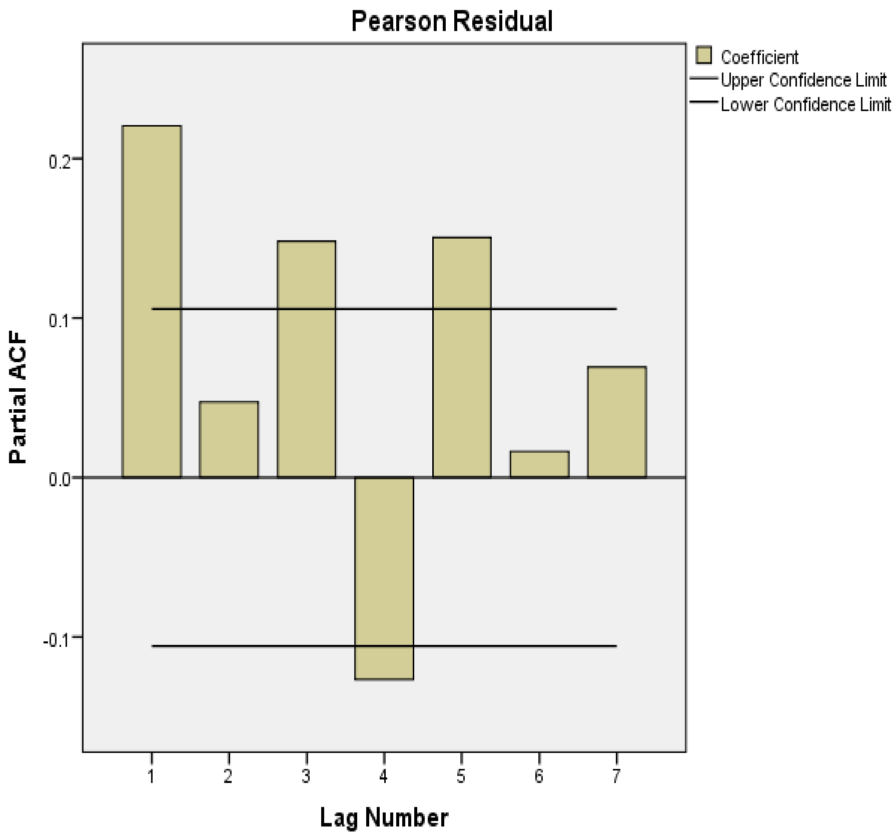
Predictor	Estimate	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (Geo)	0.0027	10	µg/m³	1.027	2.74
CO_7 (AM)	-0.1232			0.884	-11.59
NO_2_7 (AM)	-0.3535	1	mg/m³	0.702	-29.78
Temperature_7 (Mean)	0.0182			1.018	1.84
Rainfall_7 (Mean)	-0.0127	1	%	0.987	-1.26
Non-Saturdays*	0.319	1	-	1.376	37.58
*Categorical variable					

Table 62: ARI effect model (all addresses inclusive): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=616.9 at 357 df; Residual Deviance:515.2 at 351 df Omnibus test: highly significant with log likelihood chi-square: (107.7 at 6 df; p <0.0001)	Good
Multicollinearity	VIFs < 3.5	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations at 1, 3, 4 and 5 lags
Normality	KS test for deviance residual with p =0.64; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected




4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
8
10
12
14
16
18
20
Predicted Value of Mean of Response


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.2
0.1
0.0
-0.1
Partial ACF
1
2
3
4
5
6
7
Lag Number

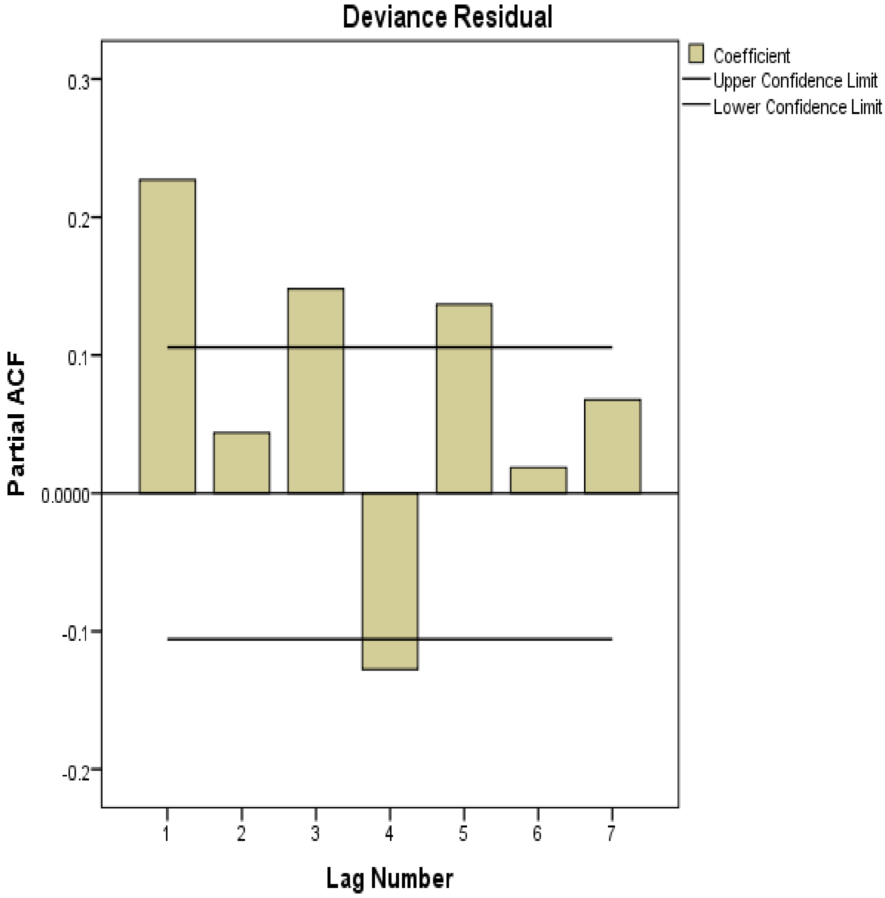


Figure 43: ARI effect model (all addresses inclusive): Model adequacy tests

3.3.3.2 Autoregressive ARI effect model (all addresses inclusive)

The ARI effect model with autoregressive terms is as follows.

Table 63: Autoregressive ARI effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.530	.1368	1.261	1.798	124.968	1	.000
[Saturday=No]	.337	.0460	.247	.428	53.773	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_7(Geo)	.0028	.0008	.001	.004	11.867	1	.001
Temperature_7 (Mean)	.0131	.0042	.005	.021	9.717	1	.002
NO_2_7 (AM)	-.2570	.1185	-.489	-.025	4.702	1	.030
ARI_1	.0144	.0029	.009	.020	24.340	1	.000
ARI_3	.0114	.0029	.006	.017	15.504	1	.000

ARI_4	-.0061	.0030	-.012	.000	4.081	1	.043
ARI_5	.0105	.0030	.005	.016	12.436	1	.000
a. Set to zero because this parameter is redundant.							

Four autoregressive terms were added at lags 1, 3, 4, and 5. As in the case for the model without autocorrelation correction, the ARI effect model shows distributed lag effects of various predictors. $PM_{2.5}$ showed a positive 7 day geometric lag effect, CO and NO_2 showed negative 7 day arithmetic lag effects, while temperature (positive) and relative humidity (negative) showed 7 day mean effects on ARI. The coefficients reveal the following relative risks and corresponding percent changes in ARI admission per unit (as indicated) increase in predictor values (or codes).

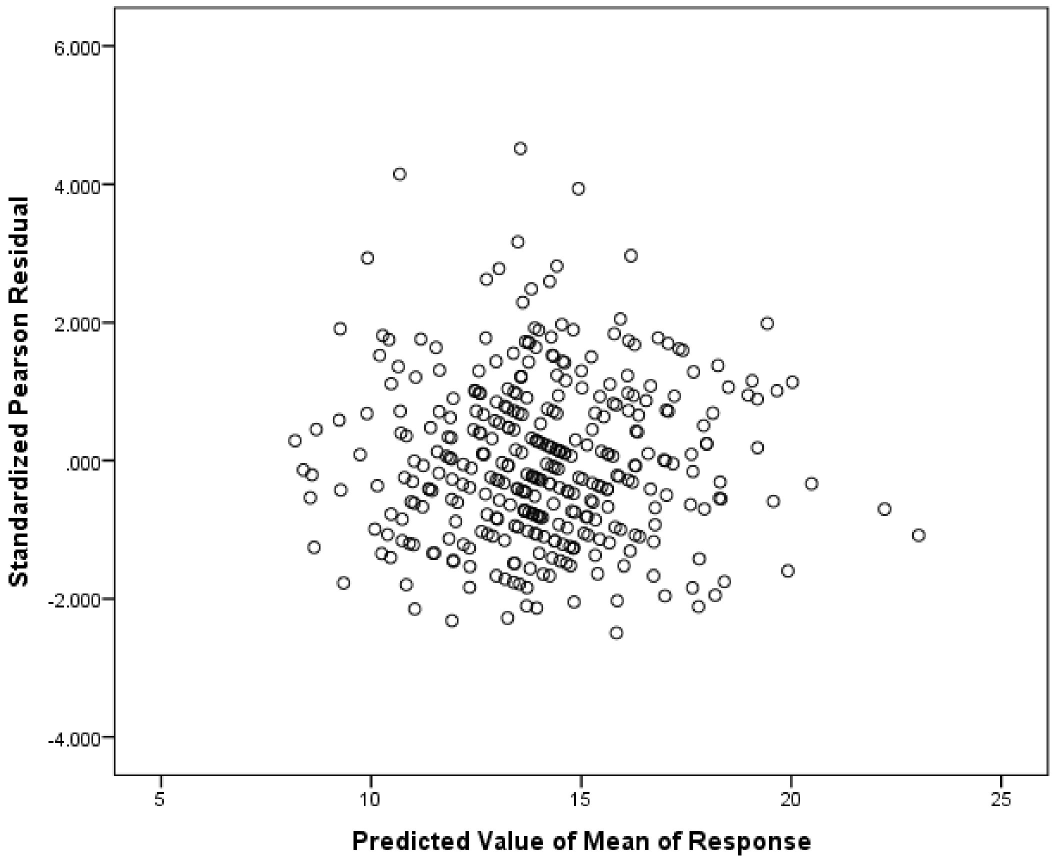
Relative risks and percent increase are given below.

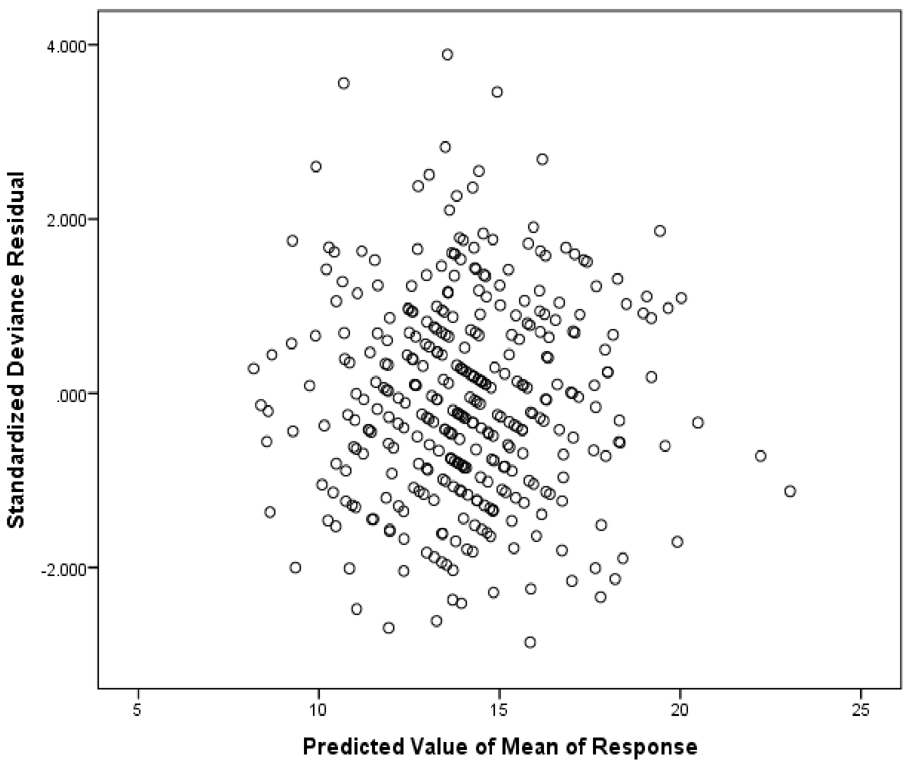
Table 64: Autoregressive ARI effect model (all addresses inclusive): Relative risks

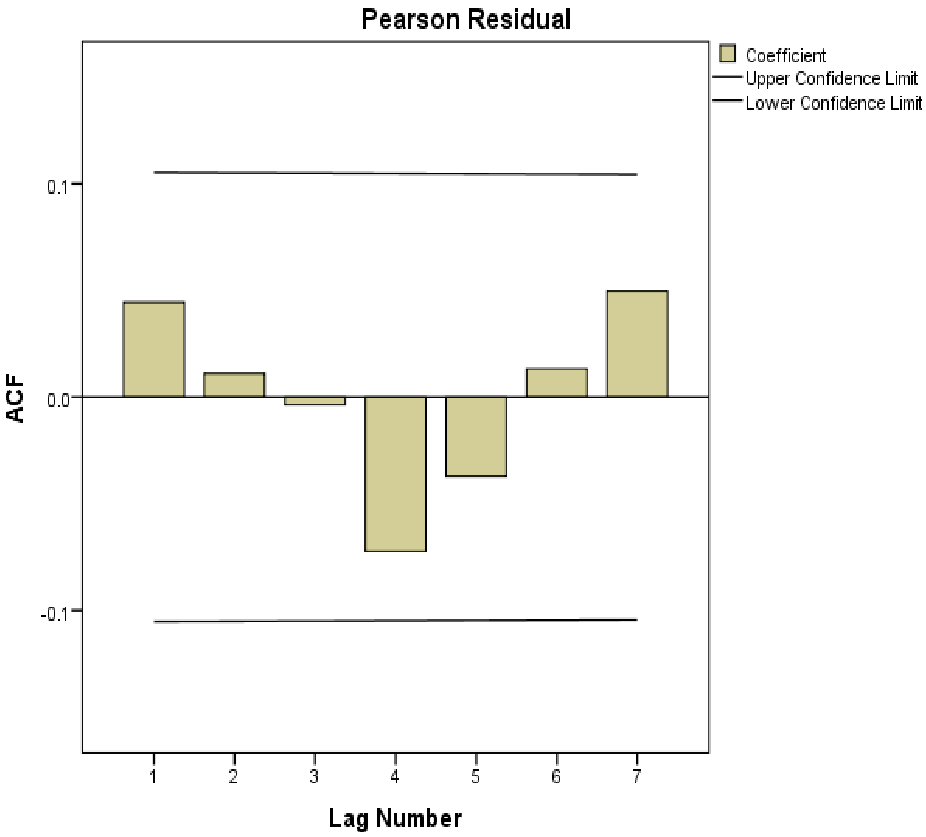
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (Geo)	0.0028	10	µg/m^3	1.028	2.84
NO_2 _7 (AM)	-0.257	1	mg/m^3	0.773	-22.66
Temperature_7 (Mean)	0.0131	1	^{0}c	1.013	1.32
Non-Saturdays*	0.337	1	-	1.401	40.07
*Categorical variable					

Table 65: Autoregressive ARI effect model (all addresses inclusive): Model adequacy tests

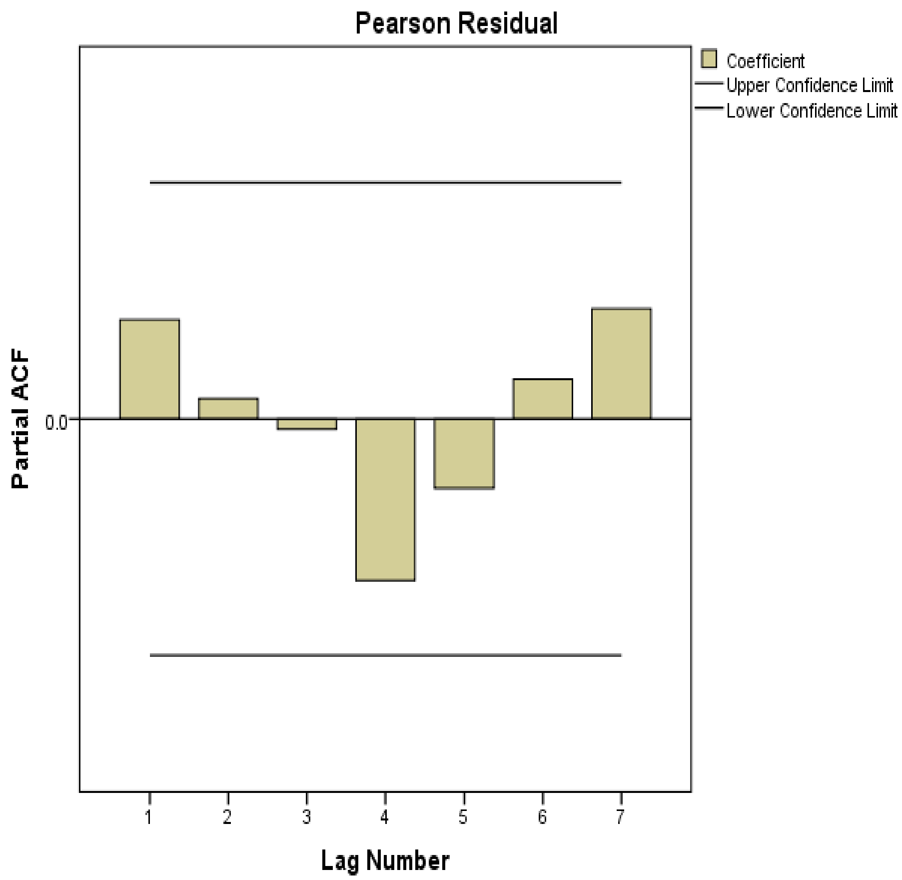
Particular	Values	Assessment
Goodness of fit	Null Deviance=616.9 at 357 df; Residual Deviance:474.5 at 349 df Omnibus test: highly significant with log likelihood chi-square: (142.4 at 8 df; p <0.0001)	Good
Multicollinearity	VIFs< 3.2	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.78; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Pearson Residual
5
10
15
20
25
Predicted Value of Mean of Response

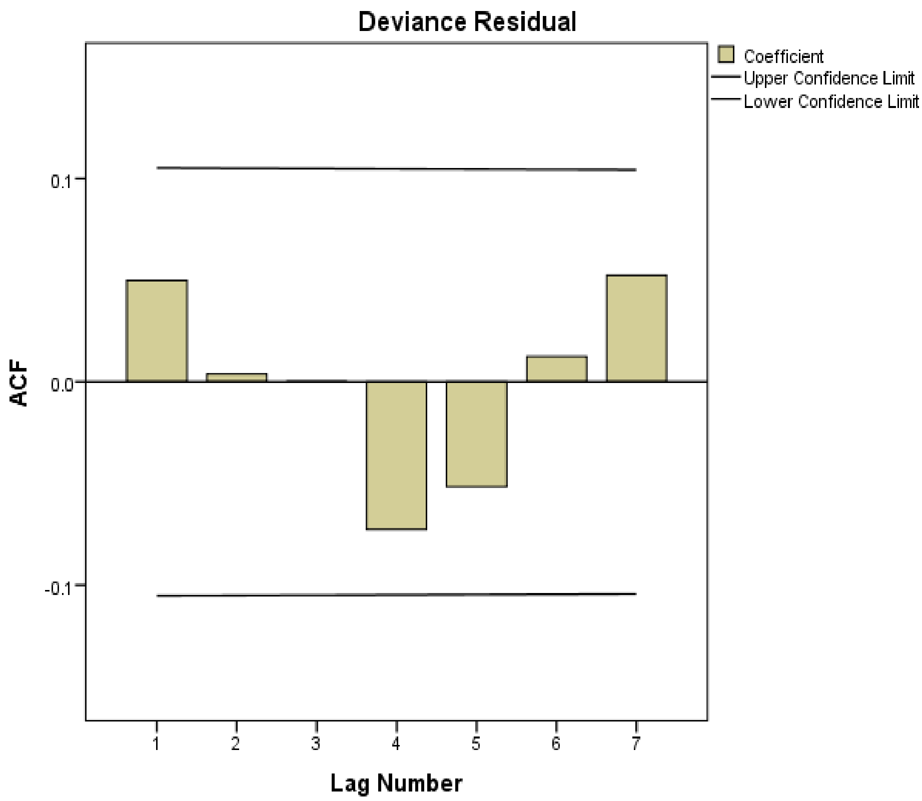

4.000
2.000
.000
-2.000
Standardized Deviance Residual
5
10
15
20
25
Predicted Value of Mean of Response



Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.1
0.0
-0.1
ACF
1
2
3
4
5
6
7
Lag Number



Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.0
Partial ACF
1
2
3
4
5
6
7
Lag Number



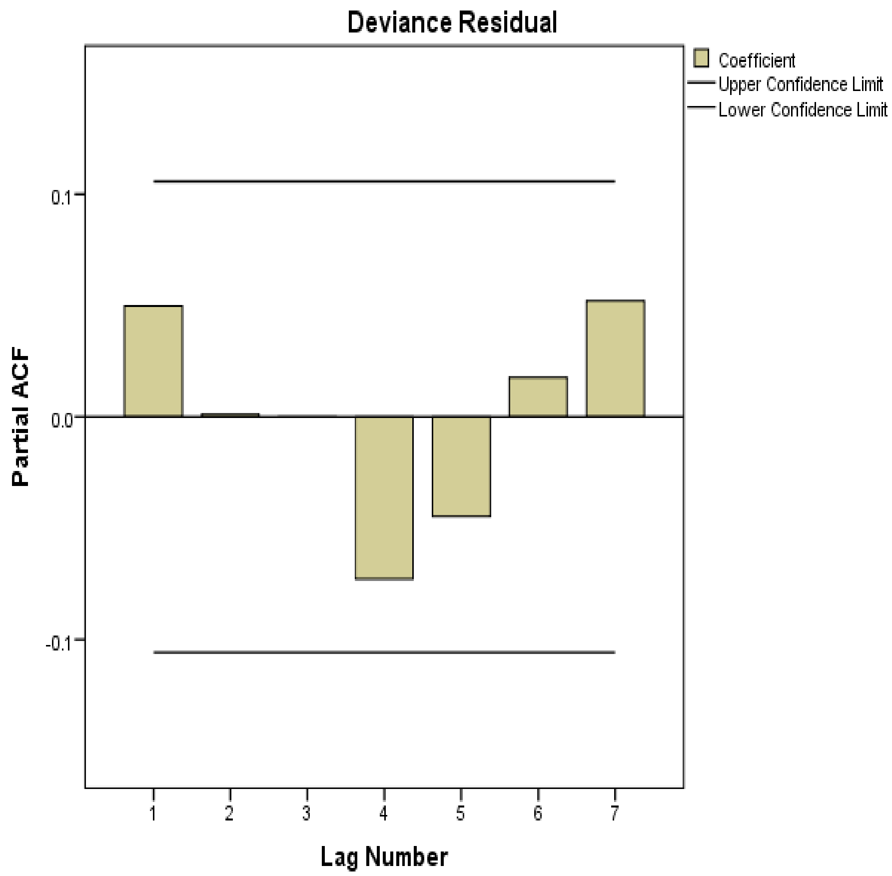


Figure 44: Autoregressive ARI effect model (all addresses inclusive): Model adequacy tests

3.3.3.3 ARI effect model (address Kathmandu Valley)

The model for inpatients with Kathmandu addresses is given below.

Table 66: ARI effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.294	.1569	.987	1.602	68.030	1	.000
[Saturday=No]	.347	.0577	.234	.460	36.194	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
NO_2_7 (Geo)	-.2946	.1329	-.555	-.034	4.911	1	.027
Temperature_7 (Geo)	.0239	.0048	.014	.033	24.478	1	.000
Rainfall_7 (Geo)	-.0109	.0042	-.019	-.003	6.685	1	.010
PM_2 (Mean)	.0027	.0009	.001	.005	8.790	1	.003
a. Set to zero because this parameter is redundant.							

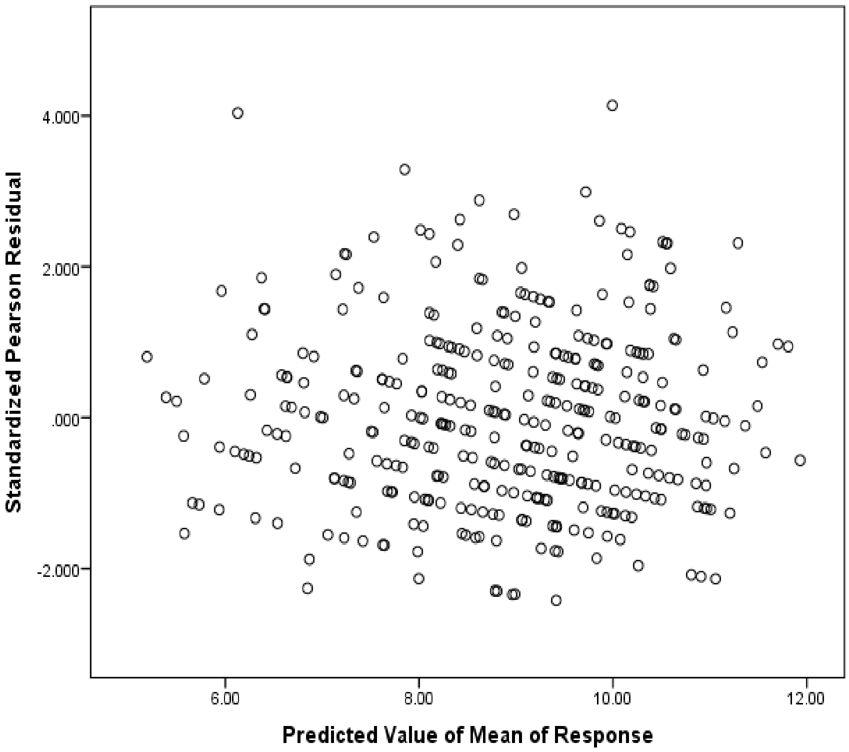
Distributed lag effects of $PM_{2.5}$ (2 day mean effect), NO_2 (1 week geometric lag effect) temperature (1 week geometric lag effect) and rainfall (1 week geometric lag effect) are found to significantly influence ARI hospital admissions for inpatients with Kathmandu Valley as their residential address. These above variables showed positive effects on ARI hospitalizations. However, NO_2 and rainfall are negative associated to hospitalizations. The coefficients reveal the following relative risks and corresponding percent changes in ARI admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

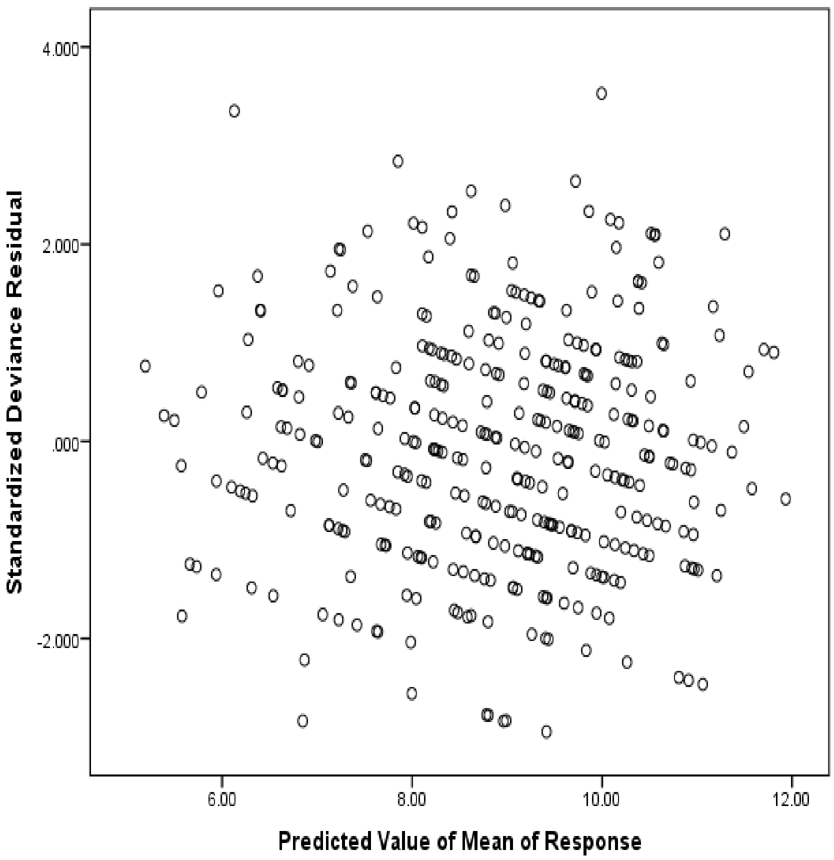
Table 67: ARI effect model (address Kathmandu valley)

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_2 (Mean)	0.0027	10	$\mu g/m^3$	1.027	2.74
NO_2 _7 (Geo)	-0.2946	1	mg/m^3	0.745	-25.52
Temperature_7 (Geo)	0.0239	1	^0c	1.024	2.42
Rain_7 (Geo)	-0.0109	1	mm	0.989	-1.08
Non-Saturdays*	0.337	1	-	1.415	41.48
*Categorical variable					

Table 68: ARI effect model (address Kathmandu valley): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=583.4 at 357 df; Residual Deviance:502.4 at 352 df Omnibus test: highly significant with log likelihood chi-square: (81.1 at 5 df; p <0.0001)	Good
Multicollinearity	VIfs< 2.8	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slight significant autocorrelations at lags 1, 2, 3, 5 and 7
Normality	KS test for deviance residual with p =0.62; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected


Standardized Pearson Residual
4.000
2.000
.000
-2.000
6.00
8.00
10.00
12.00
Predicted Value of Mean of Response


Standardized Deviance Residual
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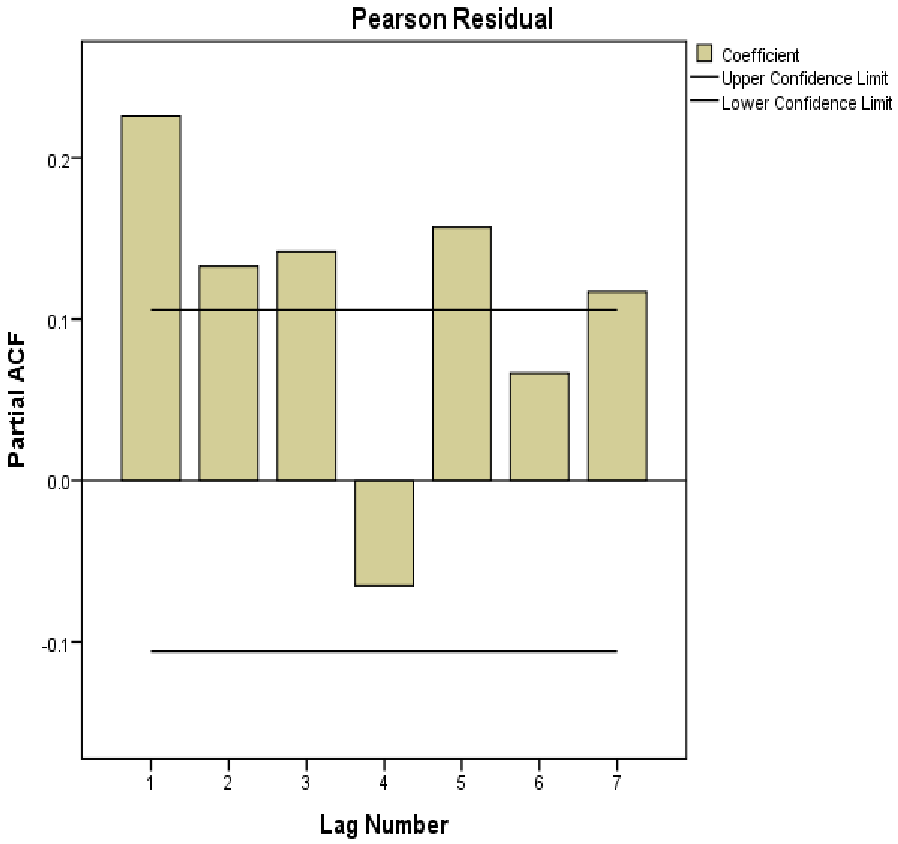
2.000
.000
-2.000
6.00
8.00
10.00
12.00
Predicted Value of Mean of Response



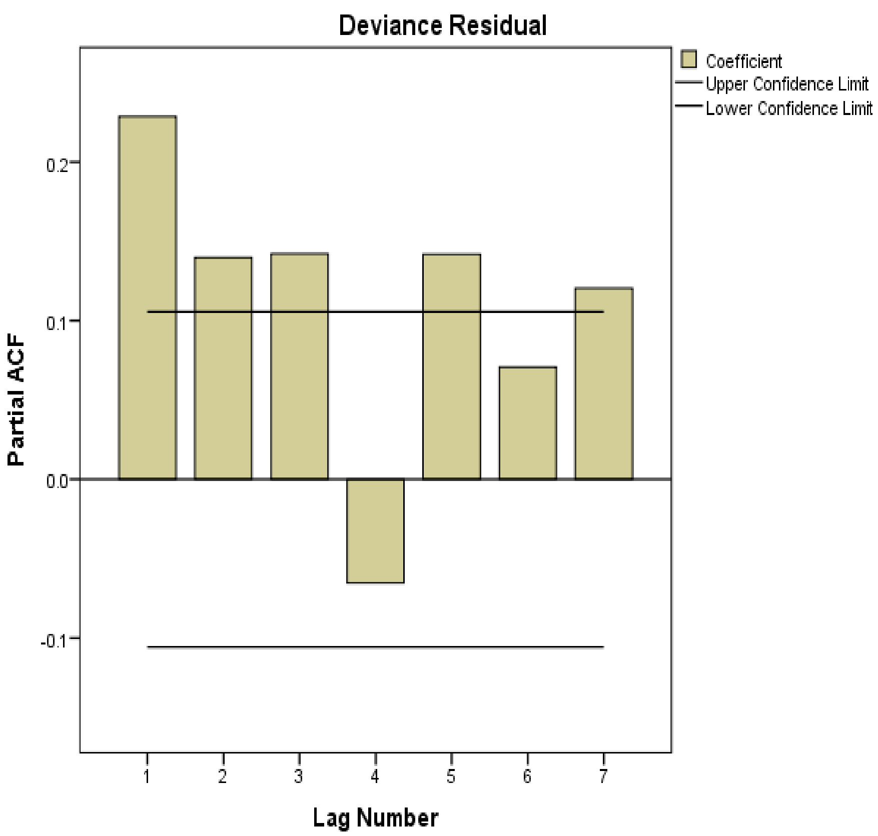


Figure 45: ARI effect model (address Kathmandu valley): Model adequacy tests

3.3.3.4 Autoregressive ARI effect model (address Kathmandu valley)

The autoregressive model is presented below.

Table 69: Autoregressive ARI effect model (address Kathmandu valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.886	.1520	.588	1.184	33.955	1	.000
[Saturday=No]	.334	.0600	.216	.451	30.913	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$ _2 (Mean)	.0020	.0008	.000	.004	5.920	1	.015
Temperature_7 (Geo)	.0142	.0049	.005	.024	8.430	1	.004
ARI_1	.0169	.0049	.007	.026	12.178	1	.000
ARI_3	.0159	.0048	.006	.025	10.960	1	.001
ARI_5	.0174	.0049	.008	.027	12.865	1	.000
ARI_7	.0141	.0050	.004	.024	8.123	1	.004
a. Set to zero because this parameter is redundant.							

Addition of autoregressive terms at different lags reduced the autocorrelations significantly. The model consists of a 2 day positive mean effect of $PM_{2.5}$, 7 day positive geometric lag effect of temperature, and positive non-Saturday effect. The coefficients reveal the following relative risks and corresponding percent changes in ARI admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

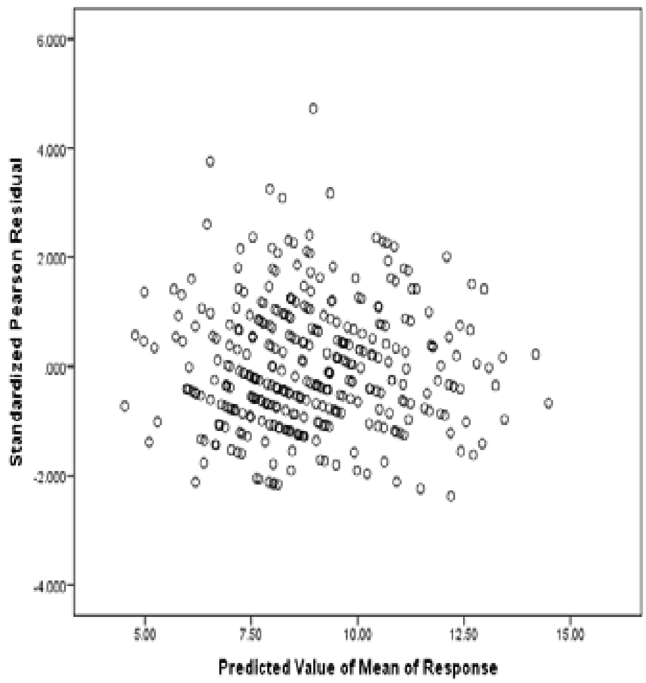
Table 70: Autoregressive ARI effect model (address Kathmandu valley): Relative risk

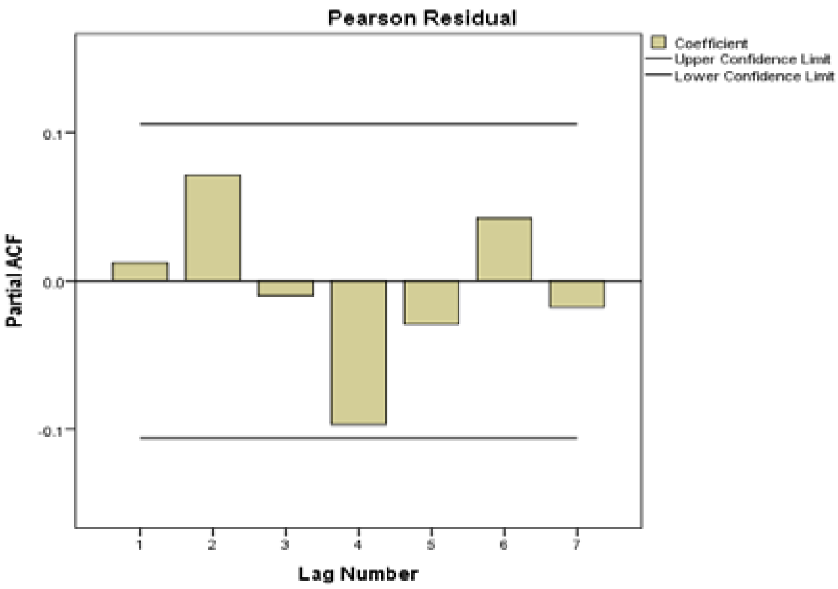
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_2 (Mean)	0.002	10	µg/m³	1.020	2.02
Temperature_7 (Geo)	0.0142	1	^{0}c	1.014	1.43
Non-Saturdays*	0.334	1	-	1.397	39.65
*Categorical variable					

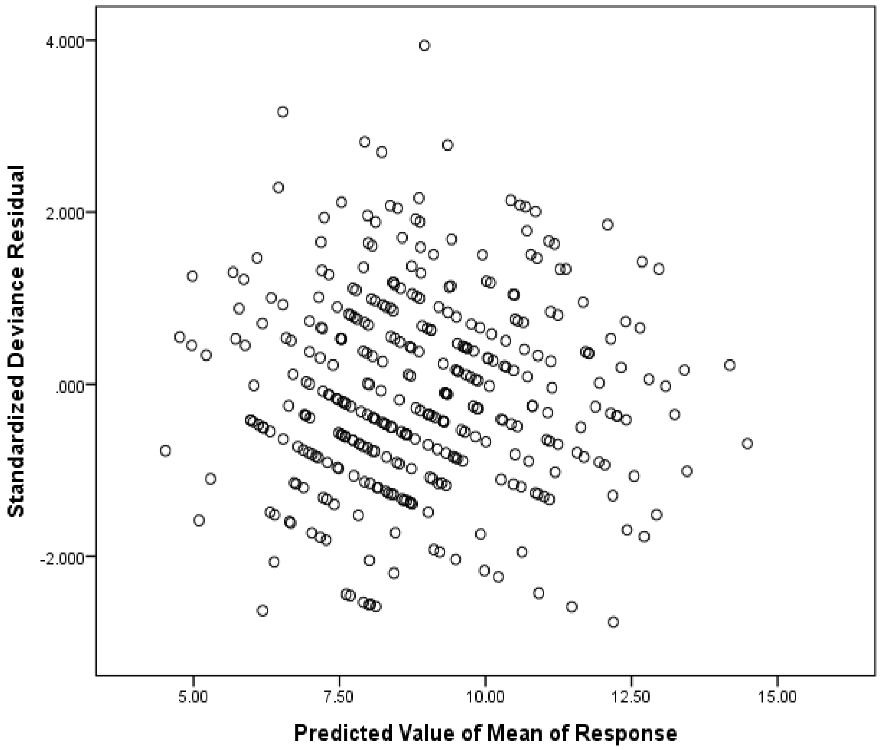
Table 71: Autoregressive ARI effect model (address Kathmandu Valley): Model adequacy tests

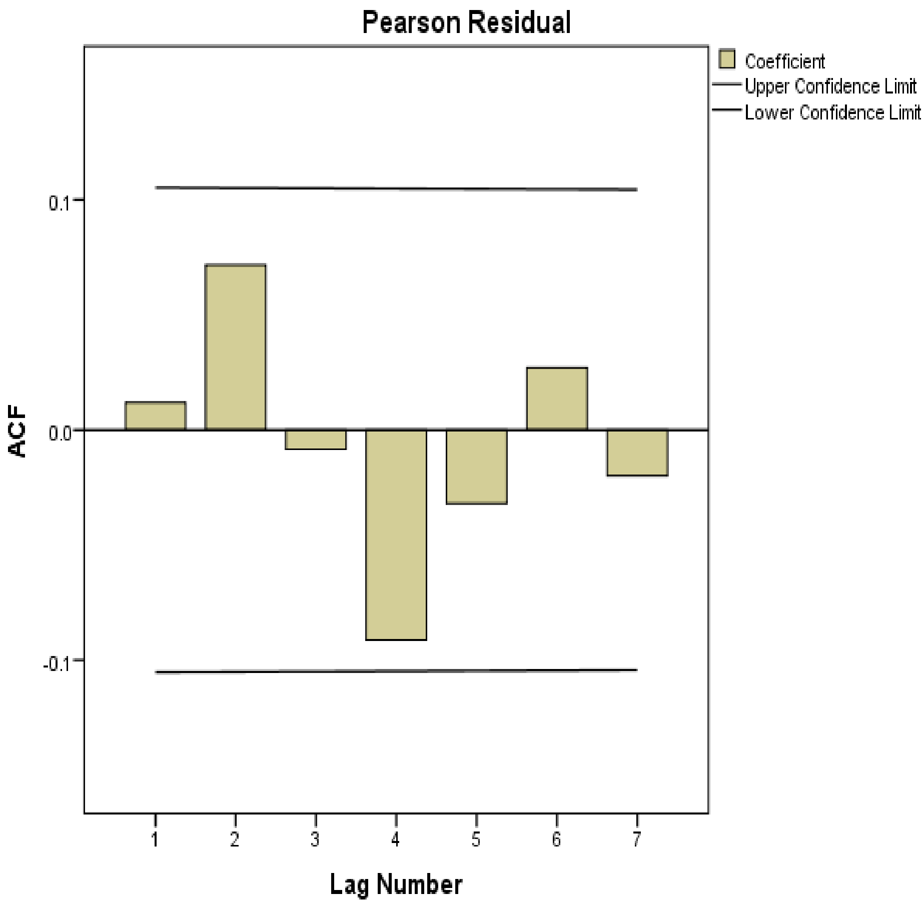
Particular	Values	Assessment
Goodness of fit	Null Deviance=583.4 at 357 df; Residual Deviance:449.3 at 350 df Omnibus test: highly significant with log likelihood chi-square: (134.1 at 7 df; p <0.0001)	Good

Multicollinearity	VIFs< 2.5	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.26; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected






4.000
2.000
.000
-2.000
Standardized Deviance Residual
5.00
7.50
10.00
12.50
15.00
Predicted Value of Mean of Response


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.1
0.0
-0.1
ACF
1
2
3
4
5
6
7
Lag Number

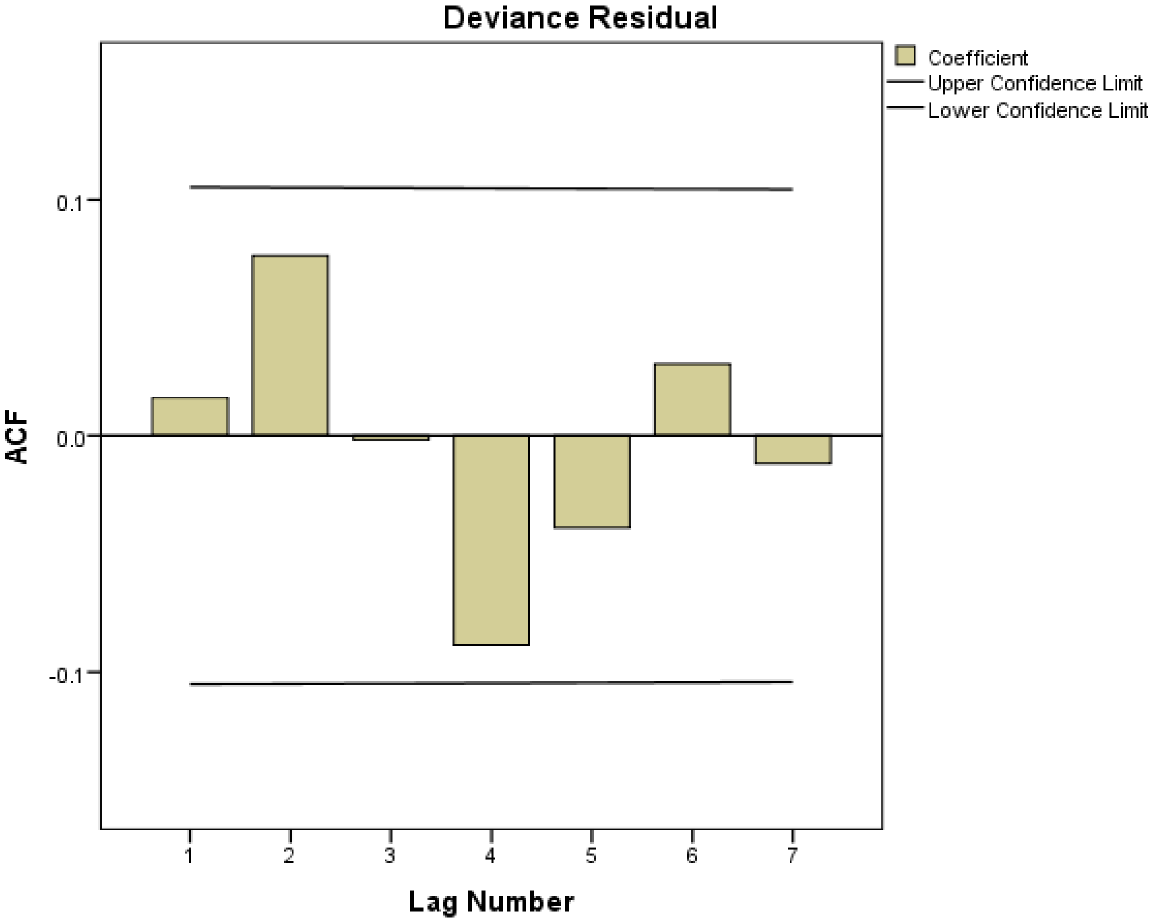


Figure: 46 Autoregressive ARI effect model (address Kathmandu valley): Model adequacy tests

3.3.3.5 Comparative assessment between ARI effect GLMs

Table 72: Comparative assessment between ARI effect GLMs

Particular	ARI		ARI (Autoregressive)		ARI KTM		ARI KTM (Autoregressive)	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	2.74 (<0.01)	7 day Geometric lag	2.84 (<0.01)	7 day Geometric lag	2.74 (<0.01)	2 day mean	2.02 (<0.02)	2 day mean
CO	-11.6 (0.02)	7 day AM lag	X		X		X	
NO_2	-29.8 (<0.01)	7 day AM lag	-22.7 (0.03)	7 day AM lag	-25.5 (<0.03)	7 day Geometric lag	X	

Temperature	1.84 (0.00)	7 day mean	1.32 (<0.01)	7 day mean	2.42 (0.00)	7 day Geometric lag	1.43 (<0.01)	7 Geometric lag
Relative Humidity	X		X		X		X	
Rainfall	-1.26 (<0.01)	7 day mean	X		-1.08 (0.01)	7 day Geometric lag	X	
Non-Saturday	37.6 (<0.01)	-	40.1 (0.00)	-	41.5 (0.00)	-	39.7 (0.00)	
Autoregressive Lag effects	-	-		1, 3, 5 (+); 4 (-)	-	-		1, 3, 5, 7 (+)

Interpretation / Assessment

Comparing the percent change in ARI hospital admissions per 10 µg/m^3 rise in $PM_{2.5}$, it is observed that the change is lower (2%) for Kathmandu residential inpatients under the autocorrelation corrected model compared to other ARI response models (around 2.7-2.8%). Additionally, a weeklong lag effect is found to be significant with models developed for all addresses inclusive, whereas 2 days mean lag effect is found to be significant for Kathmandu Valley residents. CO is found to be significant with a negative correlation only under the all-addresses inclusive model, and relative humidity is found to be statistically insignificant for all four developed ARI effect models. NO_2 is found to be negatively associated with ARI morbidity with 7 days lag effect for three of the four developed ARI effect models. Temperature is found to be positively associated with ARI hospitalizations for all four developed ARI effect models with a week-long lag effect. The change in hospitalizations for 1^0 Celsius increase in average temperature is found to vary between 1.4 and 2.4%. Rainfall is also associated with around 1-1.3% decrease in ARI hospitalizations per 1 mm increase in average rainfall for ARI models not corrected for autocorrelation. Rainfall is found to be insignificant in autoregressive models. The risk of hospitalization is greater in working days compared to holidays (i.e. Saturday) for all four developed ARI effect models, with around a 37-42% increase in hospitalizations on non-Saturdays. Slight autocorrelations are observed for the models considered for ARI hospitalizations at different lags (1, 3, 4, 5, and 7), with positive correlations of lag effects (except for 4 day lag), which is corrected for in the autoregressive GLMs.

3.3.4 Pneumonia effect models

3.3.4.1 Pneumonia effect model (all addresses inclusive)

The model with pneumonia hospitalizations as the response variable is presented below.

Table 73: Pneumonia effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.283	.1749	.940	1.626	53.769	1	.000
[Saturday=No]	.392	.0584	.278	.507	45.198	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_7 (AM)	.0046	.0011	.002	.007	16.226	1	.000
CO_4 (AM)	-.108	.0547	-.215	-.001	3.880	1	.049
NO_2_7 (AM)	-.2549	.1503	-.550	.040	2.875	1	.090
Temperature_7 (AM)	.0213	.0051	.011	.031	17.619	1	.000
Rainfall_7 (AM)	-.0131	.0049	-.023	-.004	7.151	1	.007
a. Set to zero because this parameter is redundant.							

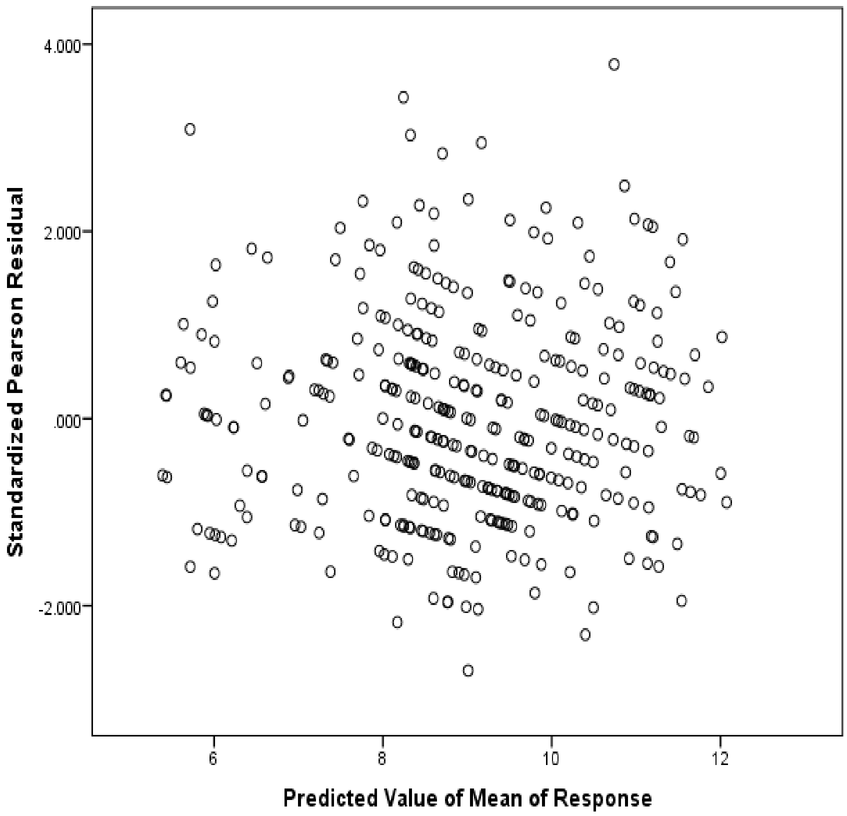
Distributed lag effects of $PM_{2.5}$ (1 week positive arithmetic lag effect), CO (4 day negative arithmetic lag effect), NO_2 (1 week negative arithmetic lag effect), temperature (1 week positive arithmetic lag effect) and rainfall (1 week negative arithmetic lag effect) are all found to have significant effects on pneumonia hospital admissions. The coefficients reveal the following relative risks and corresponding percent changes in pneumonia admission per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below

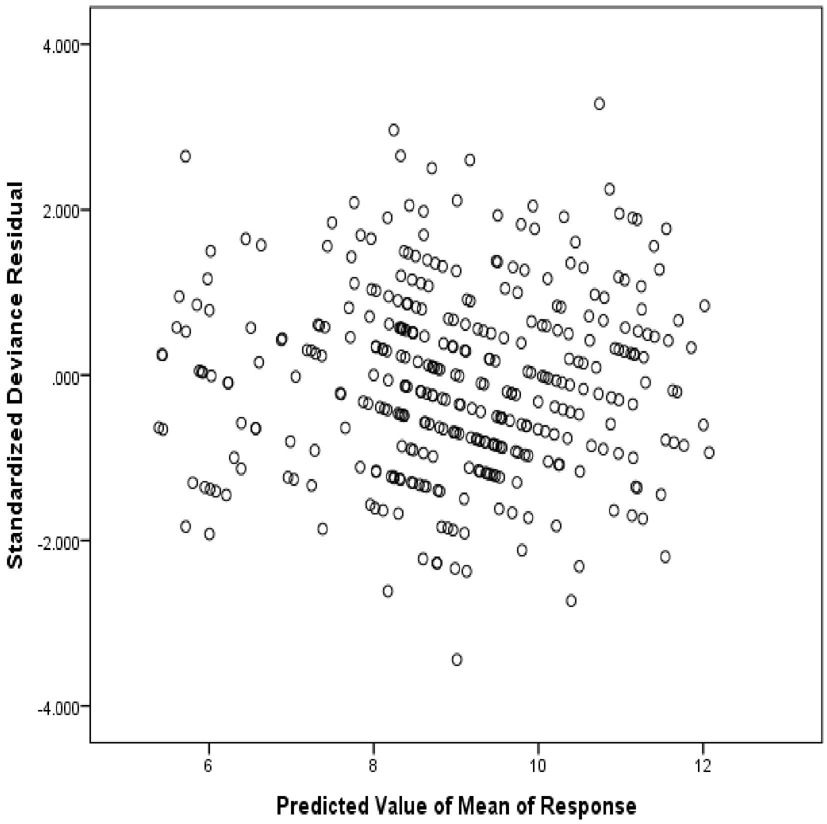
Table 74: Pneumonia effect model (all addresses inclusive): Relative risks

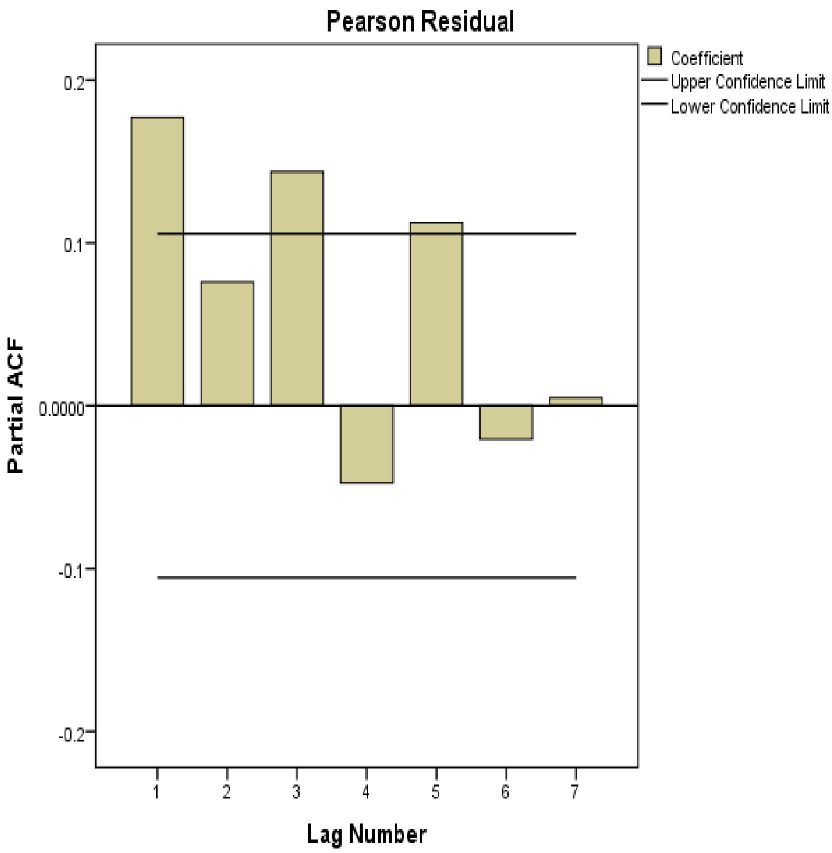
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (AM)	0.0046	10	$\mu g/m^3$	1.047	4.71
CO_4 (AM)	-0.108	1	mg/m^2	0.898	-10.24
NO_2_7(AM)	-0.2549	1	mg/m^3	0.775	-22.50
Temperature_7 (AM)	0.0213	1	^0c	1.022	2.15
Rainfall_7 (AM)	-0.0131	1	mm	0.987	-1.30
Non-Saturdays*	0.392	1	-	1.480	47.99
*Categorical variable					

Table 75: Pneumonia effect model (all addresses inclusive): Model adequacy tests

Particular	Values	Assessment
Goodness of fit	Null Deviance=518.4 at 357df; Residual Deviance:427.5 at 351 df Omnibus test: highly significant with log likelihood chi-square: (90.9 at 6 df; p <0.0001)	Good
Multicollinearity	VIFs<3.8	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	significant autocorrelations at 1, 3 and 5 lags
Normality	KS test for deviance residual with p =0.89; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected




4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
6
8
10
12
Predicted Value of Mean of Response


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.2
0.1
0.0000
-0.1
-0.2
Partial ACF
1
2
3
4
5
6
7
Lag Number

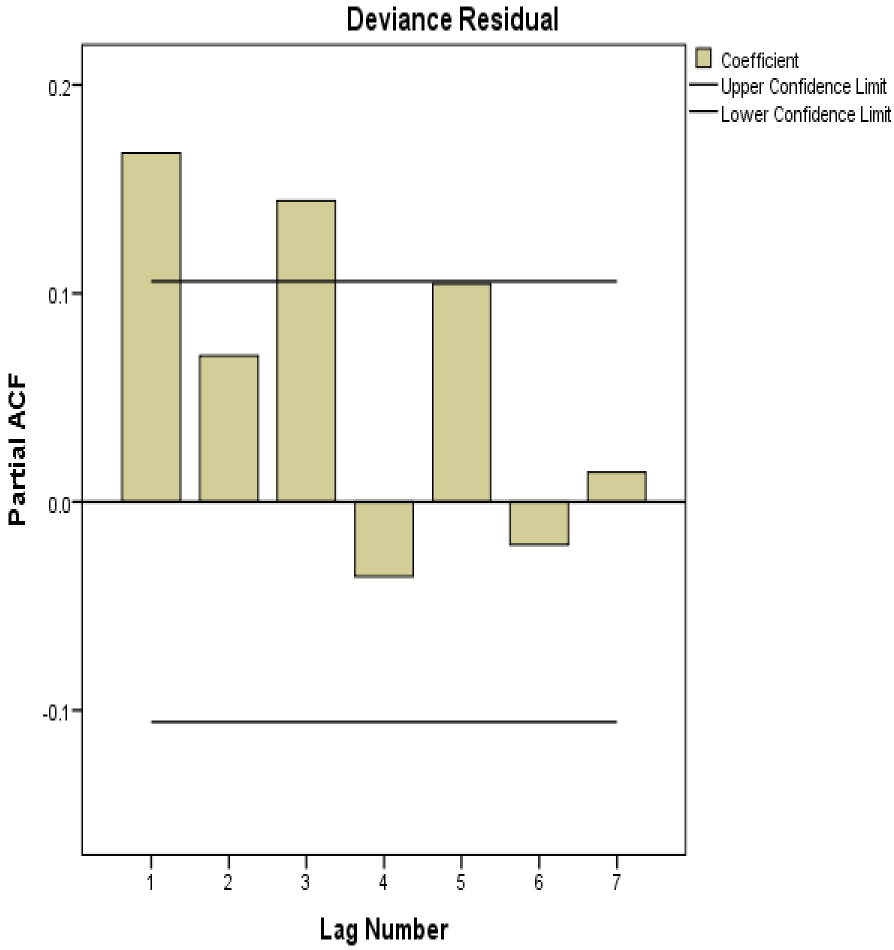


Figure 47: Pneumonia effect model (all addresses inclusive): Model adequacy tests

3.3.4.2 Autoregressive pneumonia effect model (all addresses inclusive)

The model is presented below.

Table 76: Autoregressive pneumonia effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.917	.1628	.598	1.236	31.727	1	.000
[Saturday=No]	.394	.0586	.279	.509	45.286	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$ _7 (AM)	.0032	.0010	.001	.005	10.975	1	.001
Temperature_7 (AM)	.0150	.0052	.005	.025	8.367	1	.004
Pneumonia_1	.0187	.0050	.009	.028	14.203	1	.000

Pneumonia_3	.0169	.0049	.007	.027	11.748	1	.001
Pneumonia_5	.0118	.0050	.002	.022	5.570	1	.018
a. Set to zero because this parameter is redundant.							

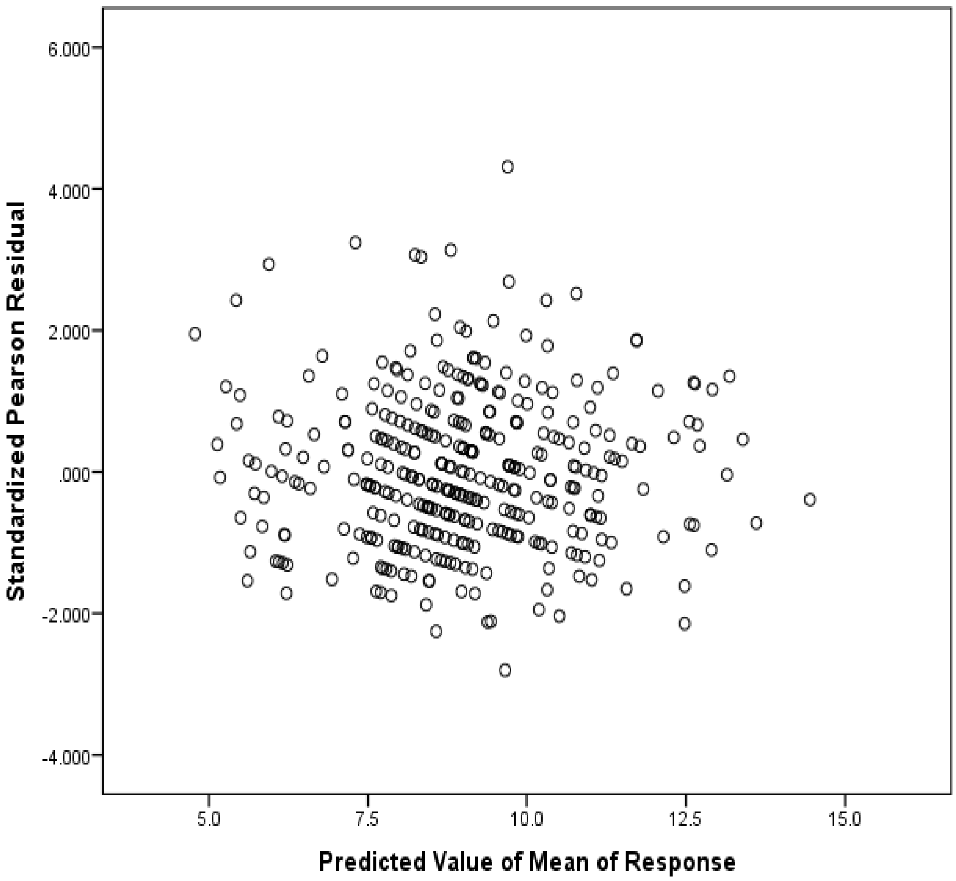
Addition of autoregressive terms at different day lags reduced the autocorrelations significantly. The model consists of a weeklong positive arithmetic lag effect of $PM_{2.5}$, 1 week positive arithmetic lag effect of temperature and a positive non-Saturday effect. The coefficients reveal the following relative risks and corresponding percent changes in pneumonia admissions per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

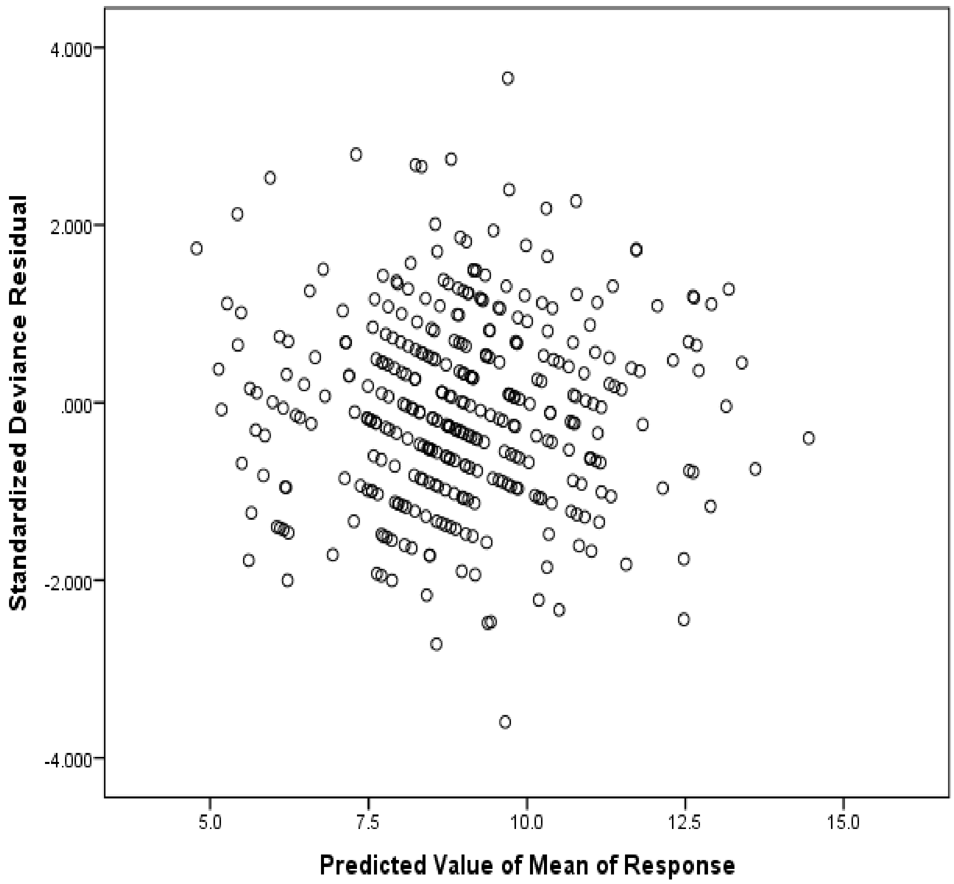
Table 77: Autoregressive pneumonia effect model (all addresses inclusive): Relative risks

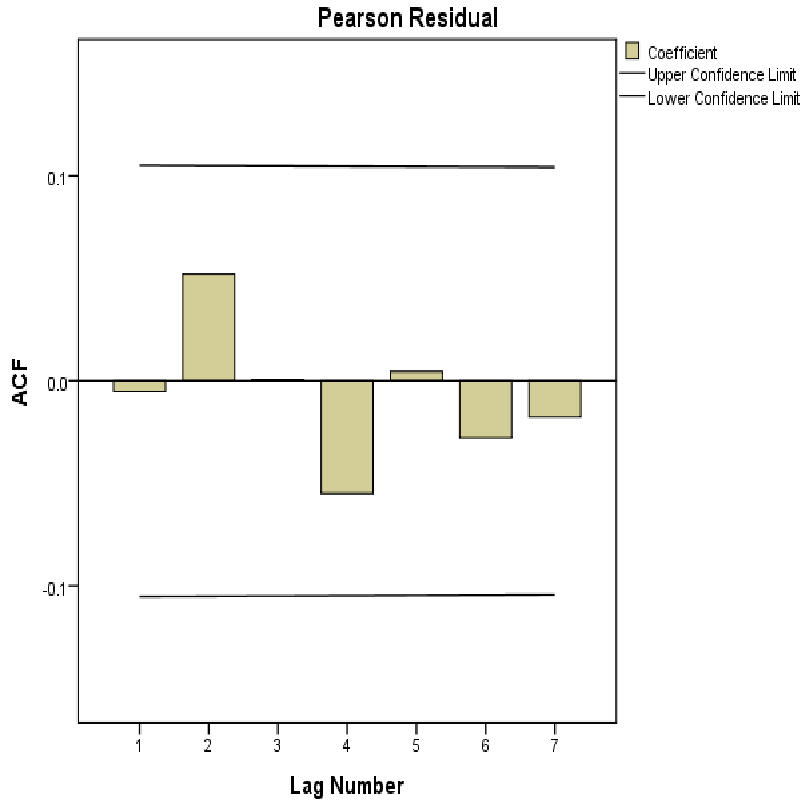
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (AM)	0.0032	10	µg/m^3	1.033	3.25
Temperature_7 (AM)	0.015	1	^{0}c	1.015	1.51
Non-Saturdays*	0.394	1	-	1.483	48.29
*Categorical variable					

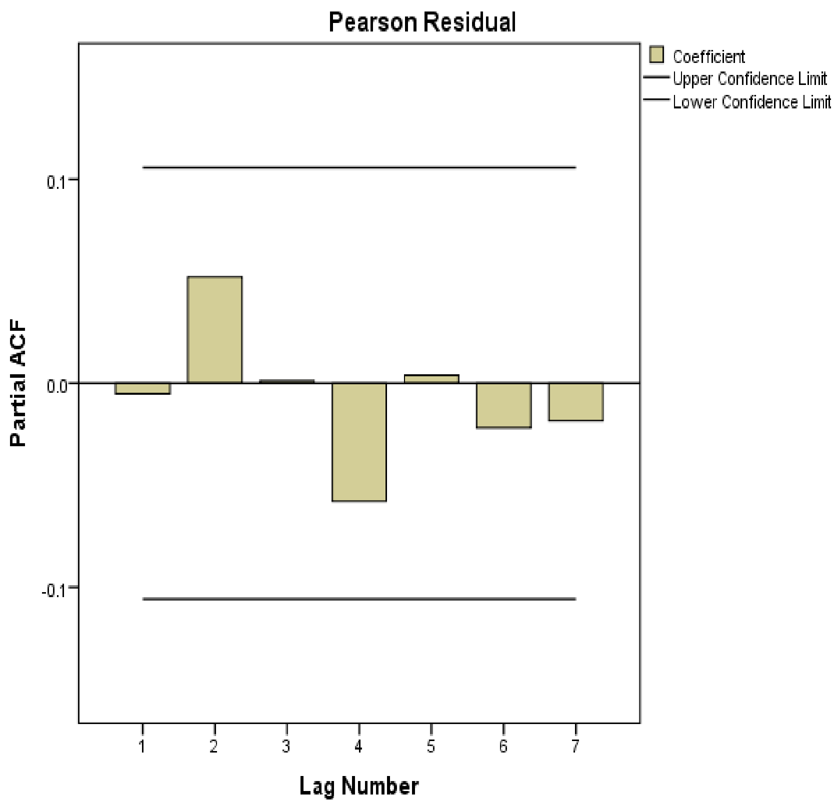
Table 78: Autoregressive pneumonia effect model (all addresses inclusive): Model adequacy tests

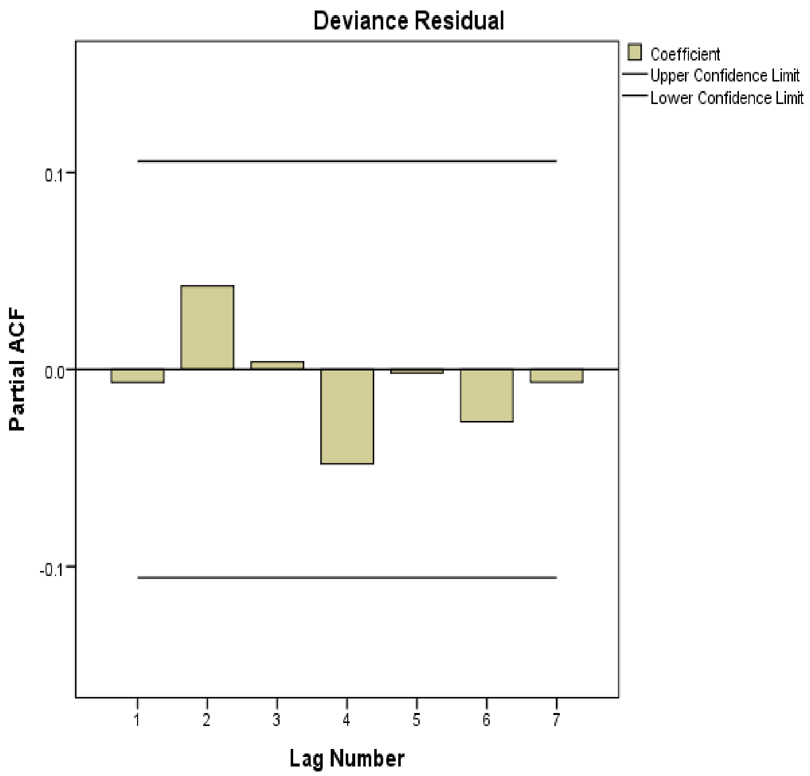
Particular	Values	Assessment
Goodness of fit	Null Deviance=518.4 at 357 df; Residual Deviance:404.7 at 351 df Omnibus test: highly significant with log likelihood chi-square: (113.7 at 6 df; p <0.0001)	Good
Multicollinearity	VIfs<3	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.98; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Pearson Residual
5.0
7.5
10.0
12.5
15.0
Predicted Value of Mean of Response


4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
5.0
7.5
10.0
12.5
15.0
Predicted Value of Mean of Response


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number



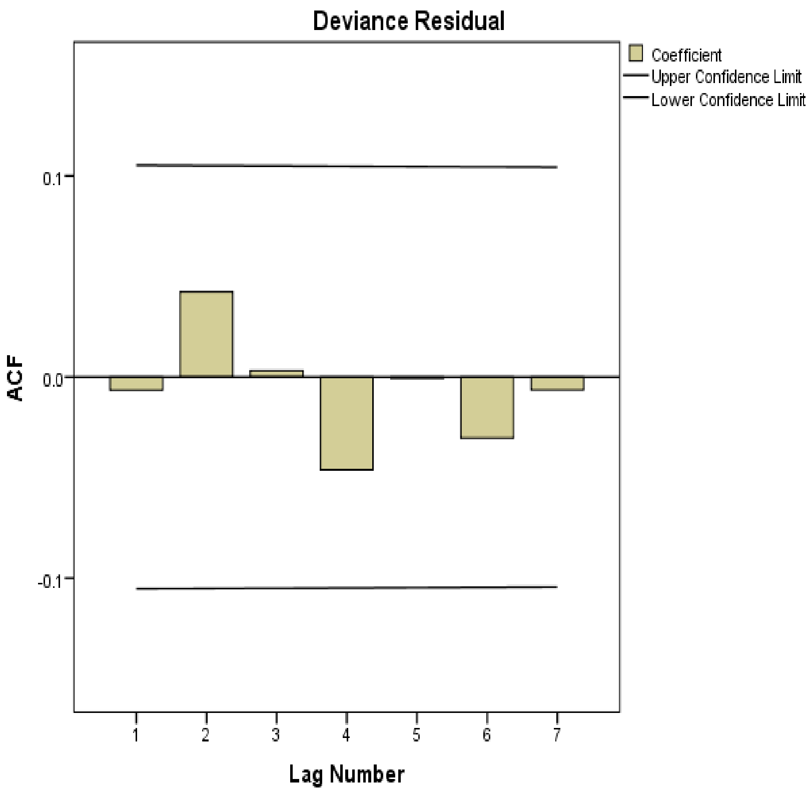


Figure 48: Autoregressive pneumonia effect model (all addresses inclusive): Model adequacy tests

3.3.4.3 Pneumonia effect model (address Kathmandu valley)

The pneumonia effect model for Kathmandu addresses is as follows.

Table 79: Pneumonia effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.922	.2054	.519	1.325	20.137	1	.000
[Saturday=No]	.356	.0721	.215	.497	24.364	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$ _7 (Geo)	.0035	.0012	.001	.006	8.290	1	.004
CO_7 (Geo)	-.1421	.0731	-.285	.001	3.782	1	.052
Temperature_7 (Geo)	.0202	.0060	.008	.032	11.174	1	.001
Rainfall_7 (Geo)	-.0165	.0055	-.027	-.006	8.890	1	.003
a. Set to zero because this parameter is redundant.							

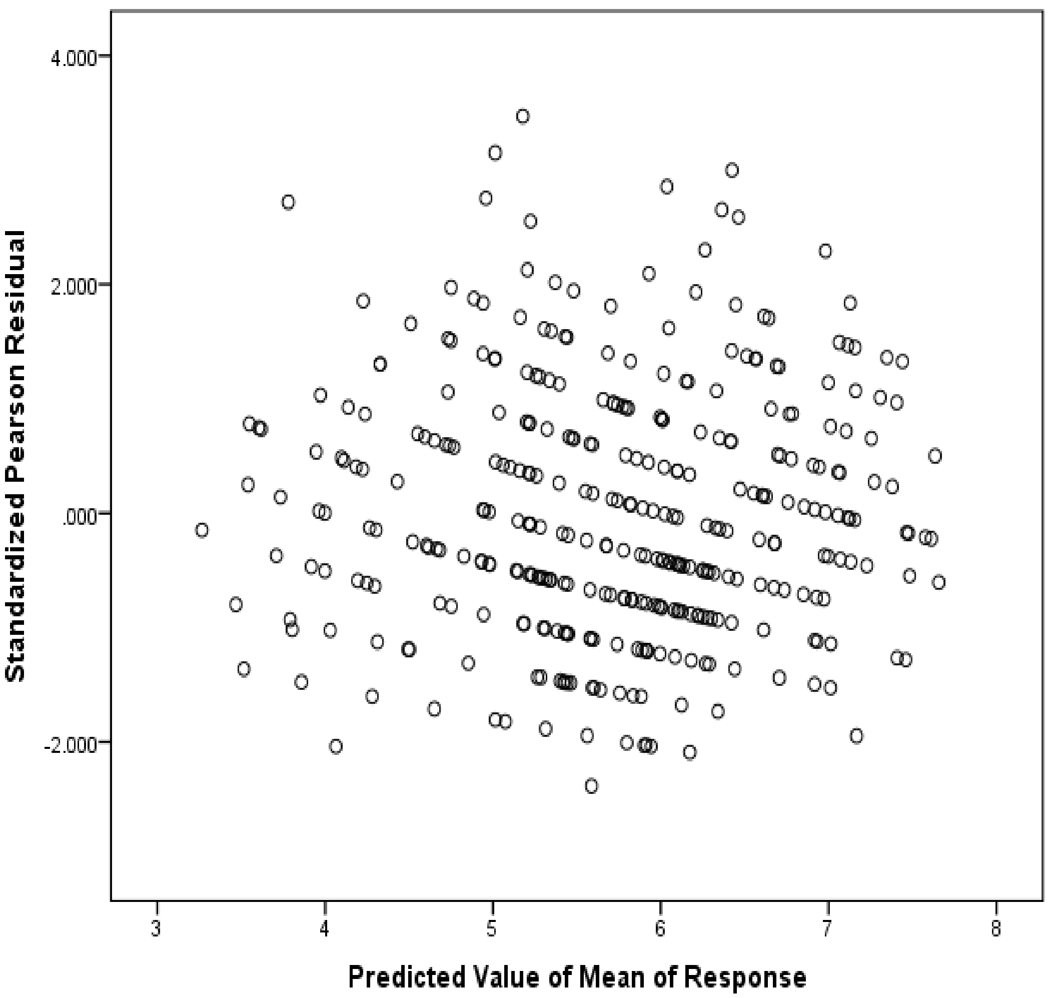
Weeklong geometric distributed lag effects of $PM_{2.5}$ (positive), CO (negative), temperature (positive) and rainfall (negative) are found to be significant for pneumonia hospital admissions for inpatients within Kathmandu Valley as their residential address. The coefficients reveal the following relative risks and corresponding percent changes in pneumonia admissions per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

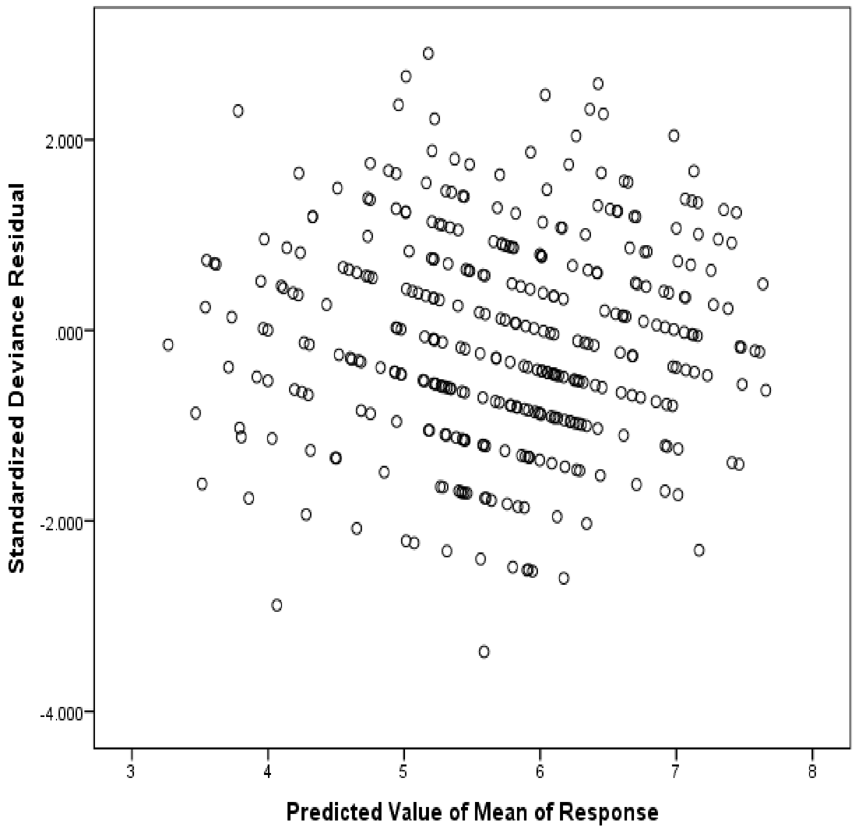
Table 80: Pneumonia effect model (address Kathmandu Valley): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (Geo)	0.0035	10	$\mu g/m^3$	1.036	3.56
C0_7 (Geo)	-0.1421	1	mg/m^3	0.868	-13.25
Temperature_7 (Geo)	0.0202	1	^0c	1.020	2.04
Rain_7 (Geo)	-0.0165	1	mm	0.984	-1.64
Non-Saturdays*	0.356	1	-	1.428	42.76
*Categorical variable					

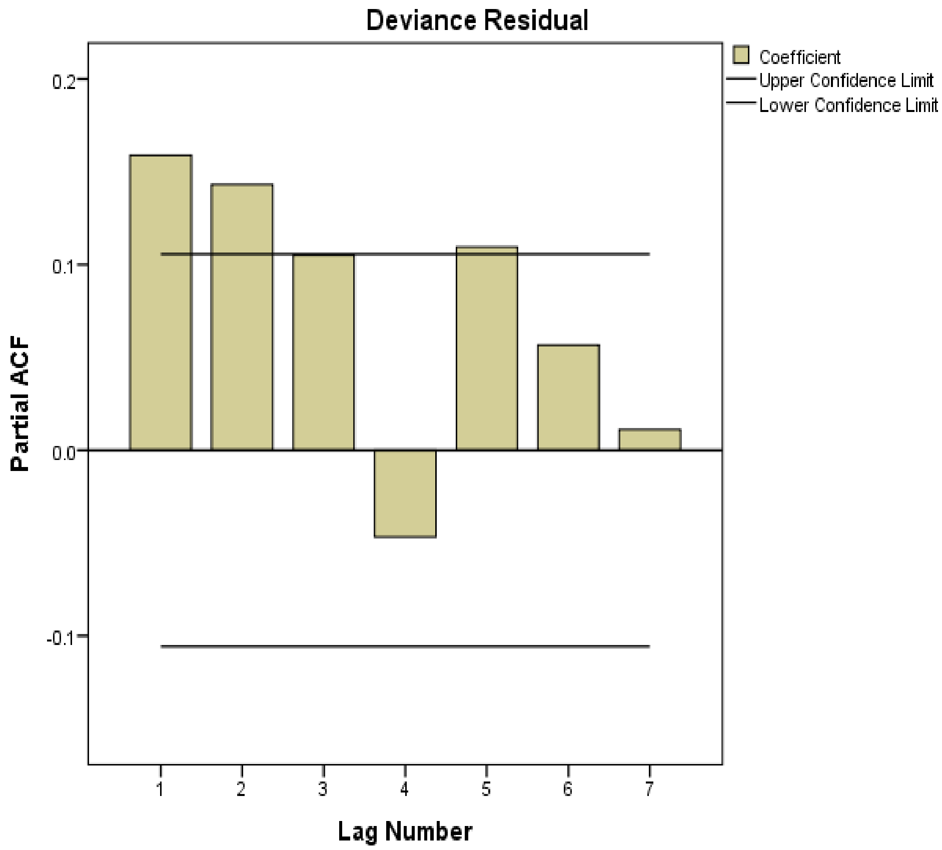
Table 81: Pneumonia effect model (address Kathmandu valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=493.2 at 357 df; Residual Deviance:436.6 at 352 df Omnibus test: highly significant with log likelihood chi-square: (56.6 at 5 df; p <0.0001)	Good
Multicollinearity	VIfs<3	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations at 1, 2, and 5 lags
Normality	KS test for deviance residual with p =0.61; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Not detected





Standardized Deviance Residual
2.000
.000
-2.000
-4.000
3
4
5
6
7
8
Predicted Value of Mean of Response



Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
0.2
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number

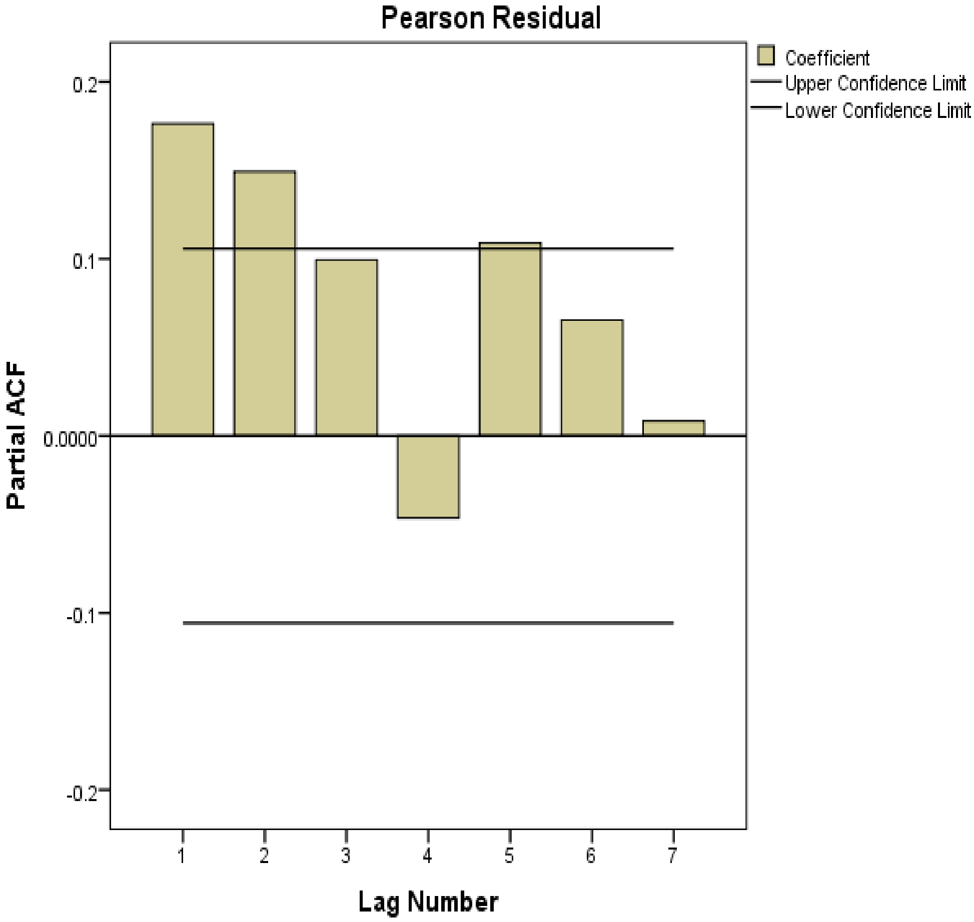


Figure 49: Pneumonia effect model (address Kathmandu valley): Model adequacy test

3.3.4.4 Autoregressive pneumonia effect model (address Kathmandu Valley)

Table 82: Autoregressive pneumonia effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	**β**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**
(Intercept)	.484	.1953	.101	.867	6.137	1	.013
[Saturday=No]	.395	.0725	.253	.537	29.700	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$ _7 (Geo)	.0033	.0011	.001	.006	8.306	1	.004
Temperature_7 (Geo)	.0137	.0061	.002	.026	5.017	1	.025
Pneumonia_1	.0301	.0083	.014	.046	13.304	1	.000
Pneumonia_2	.0224	.0082	.006	.038	7.457	1	.006
Pneumonia_5	.0231	.0082	.007	.039	7.875	1	.005
a. Set to zero because this parameter is redundant.							

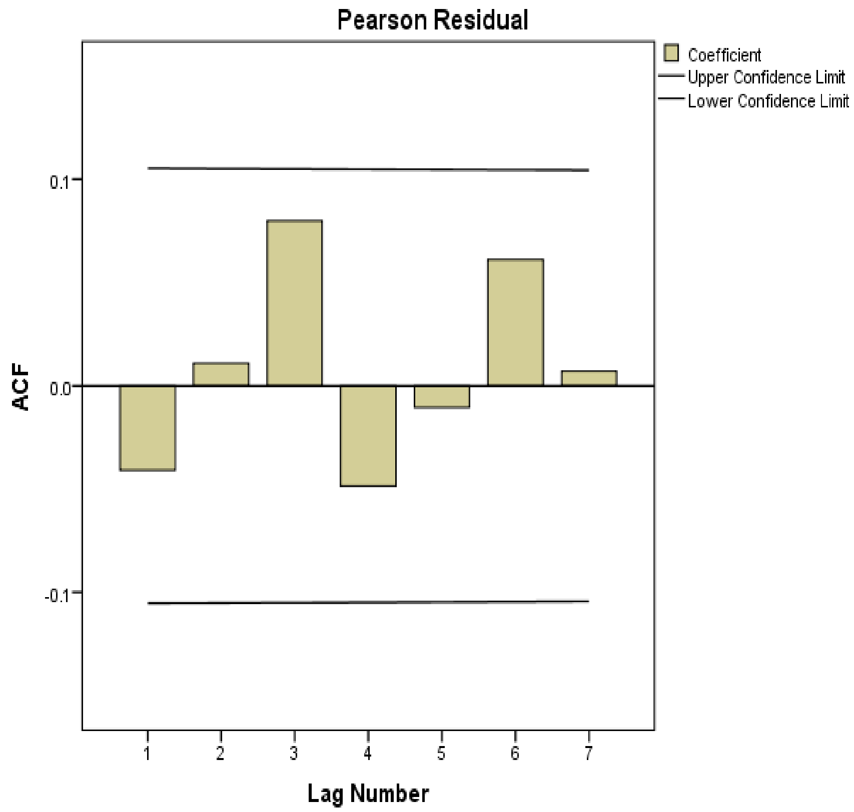
Addition of autoregressive terms at different lag times (1, 2, and 5 day lags) reduced the autocorrelations significantly. The autocorrelation-corrected model consists of 1 week positive geometric distributed lag effects of $PM_{2.5}$ and temperature and a positive non-Saturday effect. The coefficients reveal the following relative risks and corresponding percent changes in pneumonia admissions per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

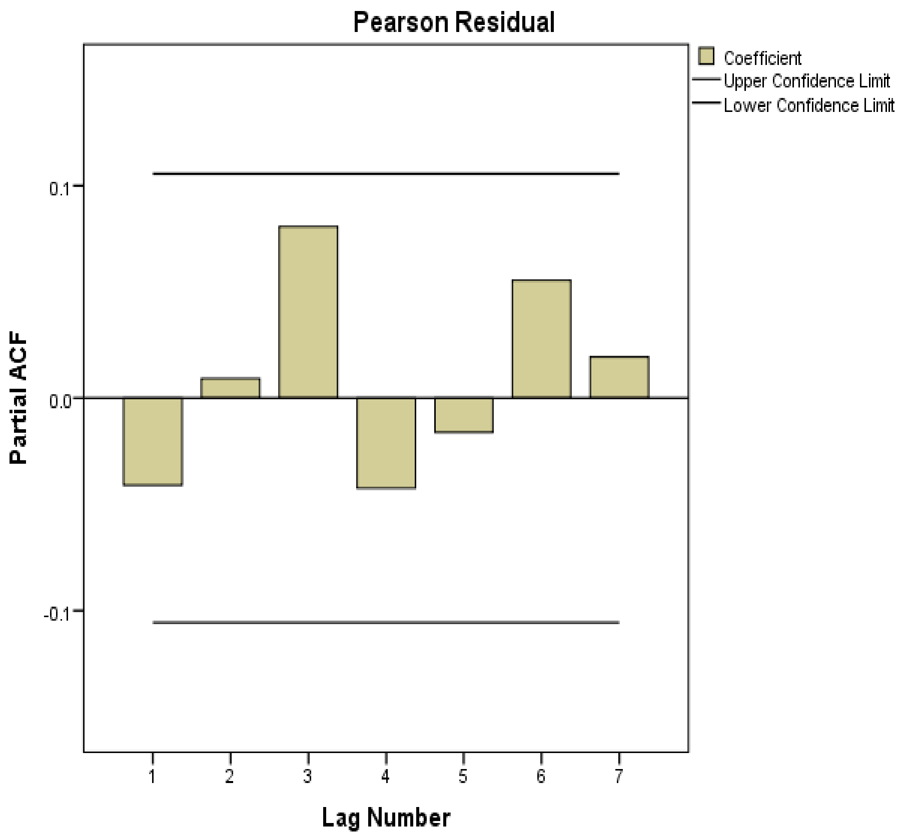
Table 83: Autoregressive pneumonia effect model (address Kathmandu valley): Relative risks

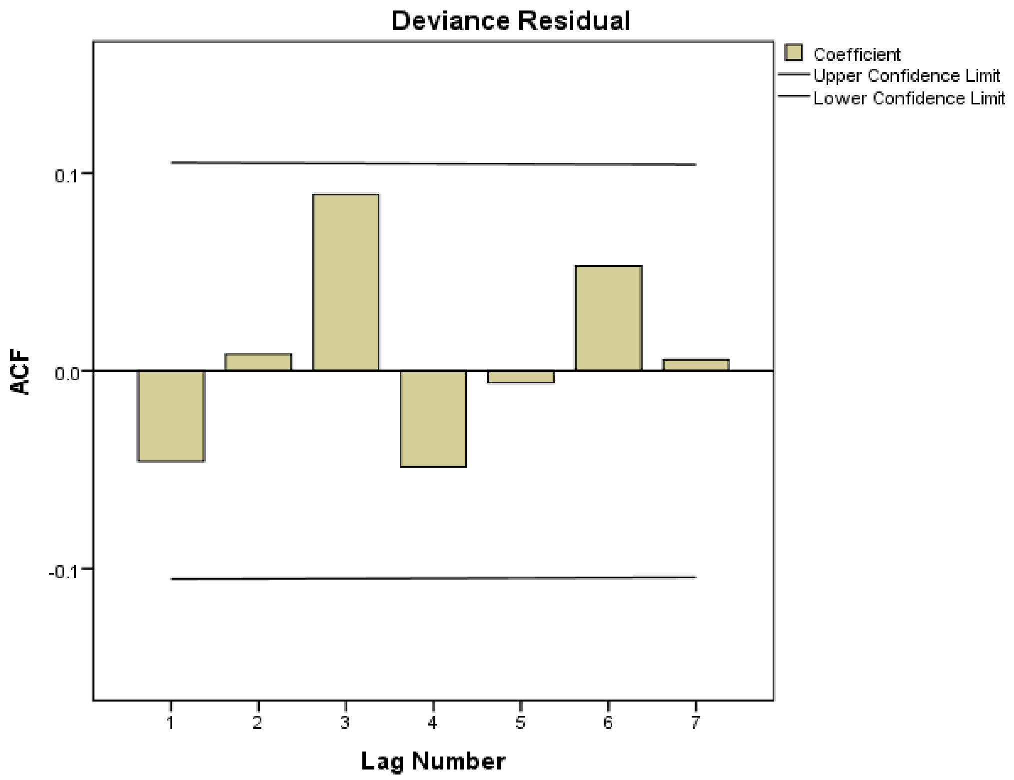
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (Geo)	0.0033	10	$\mu g/m^3$	1.034	3.36
Temperature_7 (Geo)	0.0137	1	^0c	1.014	1.38
Non-Saturdays*	0.395	1	-	1.484	48.44
*Categorical variable					

Table 84: Autoregressive pneumonia effect model (address Kathmandu valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=493.2 at 357 df; Residual Deviance:409.9 at 351 df Omnibus test: highly significant with log likelihood chi-square: (83.3 at 6 df; p <0.0001)	Good
Multicollinearity	VIfs<2.7	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.62; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
0.1
0.0
-0.1
1
2
3
4
5
6
7
Lag Number



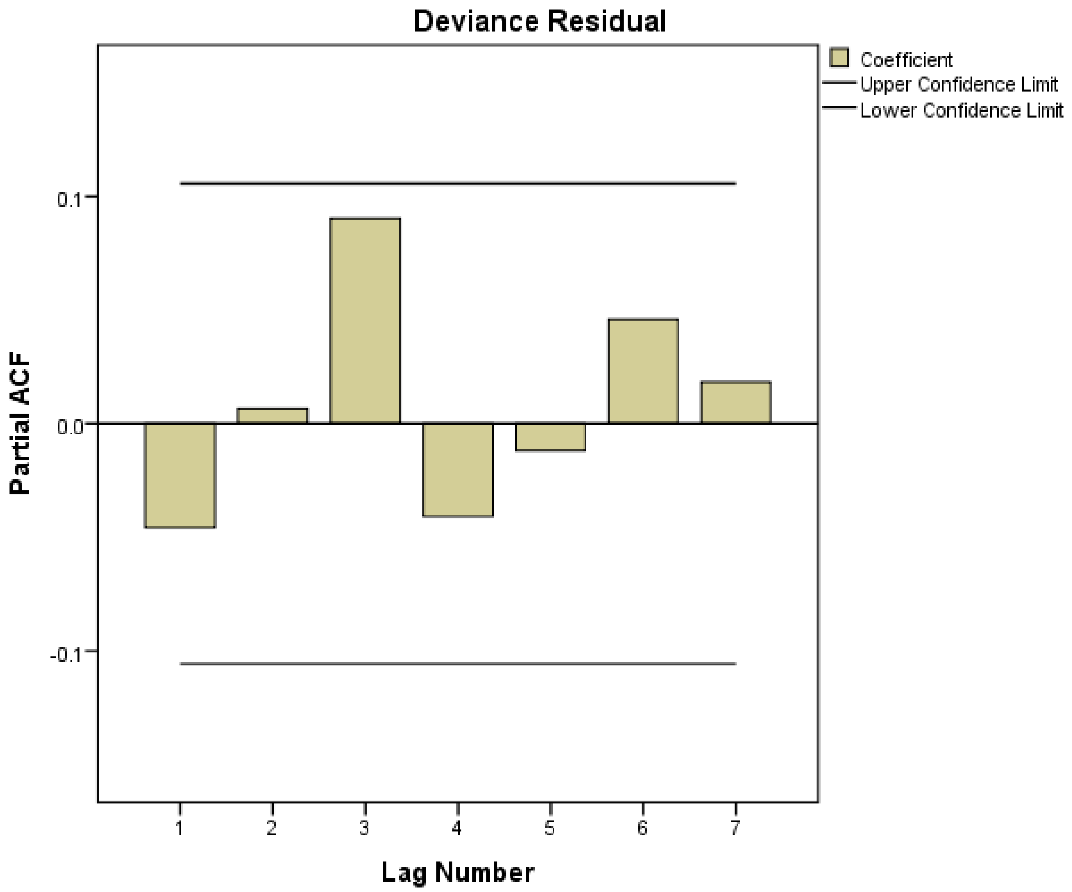


Figure 50: Autoregressive pneumonia effect model (address Kathmandu valley): Model adequacy test

3.3.4.5 Comparative assessment between pneumonia effect GLMs

Table 85: Comparative assessment between pneumonia effect GLMs

Particular	**Pneumonia**		**Pneumonia (Autoregressive)**		**Pneumonia KTM**		**Pneumonia KTM (Autoregressive)**	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	4.71 (0.00)	7 day AM lag	3.25 (<0.01)	7 day AM lag	3.56 (<0.01)	7 day Geometric lag	3.36 (<0.01)	7 day Geometric lag
CO	-10.24 (0.05)	7 day AM lag	X		-13.25 (<0.05)	7 day Geometric lag	X	
NO_2	-22.5 (<0.01)	7 day AM lag	X	_	X	_	X	_
Temperature	2.15 (0.00)	7 day AM lag	1.51 (<0.01)	7 day AM lag	2.04 (< 0.01)	7 day Geometric lag	1.38 (<0.03)	7 day Geometric lag
Relative Humidity	X	_	X	_	X	_	X	_
Rainfall	-2.15 (<0.01)	7 day AM lag	X	_	-1.64 (0.01)	7 day Geometric lag	X	_
Non-Saturday	48.0 (<0.00)	-	48.3 (0.00)	-	42.8 (0.00)	-	48.4 (0.00)	
Autoregressive Lag effects	-	-		1, 3, 5 (+)	-	-		1, 3, 5 (+)

Interpretation / Assessment

Seven day distributed lag effects are found to be statistically significant for all four developed pneumonia effect models; arithmetic decay is significant for all-addresses inclusive models, and geometric decay is significant for Kathmandu Valley addresses models. Comparing the percent change in pneumonia hospital admissions per 10 μg/m^3 rise in $PM_{2.5}$, the change is higher (4.71%) for the non-autocorrelation all-address inclusive model than for the other three models (3.3-3.6%). CO is found to be insignificant for autoregressive pneumonia effect models whereas it is negatively associated with pneumonia hospitalizations in autocorrelation ignored models. NO_2 is found to be negatively associated with only the autocorrelation ignored all-addresses inclusive model, and insignificant for the other three models. Temperature is found to be statistically significant and positively associated for all four developed pneumonia effect models, with 7 day arithmetic decay for all-addresses inclusive models and 7 day geometric decay for Kathmandu Valley addresses models. Relative humidity is found to be statistically insignificant for all four pneumonia effect models. Rainfall is negatively associated with pneumonia in autocorrelation ignored models, and insignificant in autoregressive models with 7 day lag effects. The decrease in pneumonia hospitalizations ranges from 1.6-2.2% per 1mm increase in rainfall. The risk of hospitalization is greater on working days compared to holidays (i.e. Saturdays) for all four developed pneumonia effect models with, around a 43-48% increase in hospitalizations on non-Saturdays. Slight autocorrelations are observed for the models considered for pneumonia hospitalizations at 1, 3 and 5 day lags, which is corrected for in the autoregressive GLMs.

3.3.5 Children and adolescents respiratory effect models

Models for children and adolescents aged 19 or less are presented in this section.

3.3.5.1 Children and adolescents respiratory effect model (all addresses inclusive)

The model is presented below.

Table 86: Children and adolescents respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	2.313	.0759	2.164	2.462	928.828	1	.000
[Saturday=No]	.247	.0536	.142	.352	21.290	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
[Autumn=No]	-.0897	.0436	-.175	-.004	4.237	1	.040
[Autumn=Yes]	0[a]	.	.	.	.	.	.
[Winter=No]	-.1186	.0472	-.211	-.026	6.323	1	.012
[Winter=Yes]	0[a]	.	.	.	.	.	.
NO_2_7 (AM)	-.7351	.1455	-1.020	-.450	25.544	1	.000
a. Set to zero because this parameter is redundant.							

The statistical model with respiratory hospitalizations as the response variable developed for children and the adolescent population (ages ≤19) shows that seasonal variables like autumn and winter, along with non-Saturdays are found to be statistically significant indicators. Additionally, a weeklong arithmetic distributed lag effect of NO_2 is also statistically significant. Relative risks estimates and percent increases are given below.

Table 87: Children and adolescents respiratory effect model (all addresses inclusive): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
NO_2_7 (AM)	-0.7351	1	mg/m^3	0.479	-52.05
Non-Saturdays*	0.247	1	-	1.280	28.02
Not Autumn*	-0.0897	1	-	0.914	-8.58
Not Winter*	-0.1186	1	-	0.888	-11.18
*Categorical variable					

Table 88: Children & adolescents respiratory effect model (all addresses inclusive): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=557.2 at 357 df; Residual Deviance:488.3 at 353 df Omnibus test: highly significant with log likelihood chi-square: (68.9 at 4 df; p <0.0001)	Good
Multicollinearity	VIfs<1.6	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations 1 and 5 lags
Normality	KS test for deviance residual with p =0.46, normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Not detected

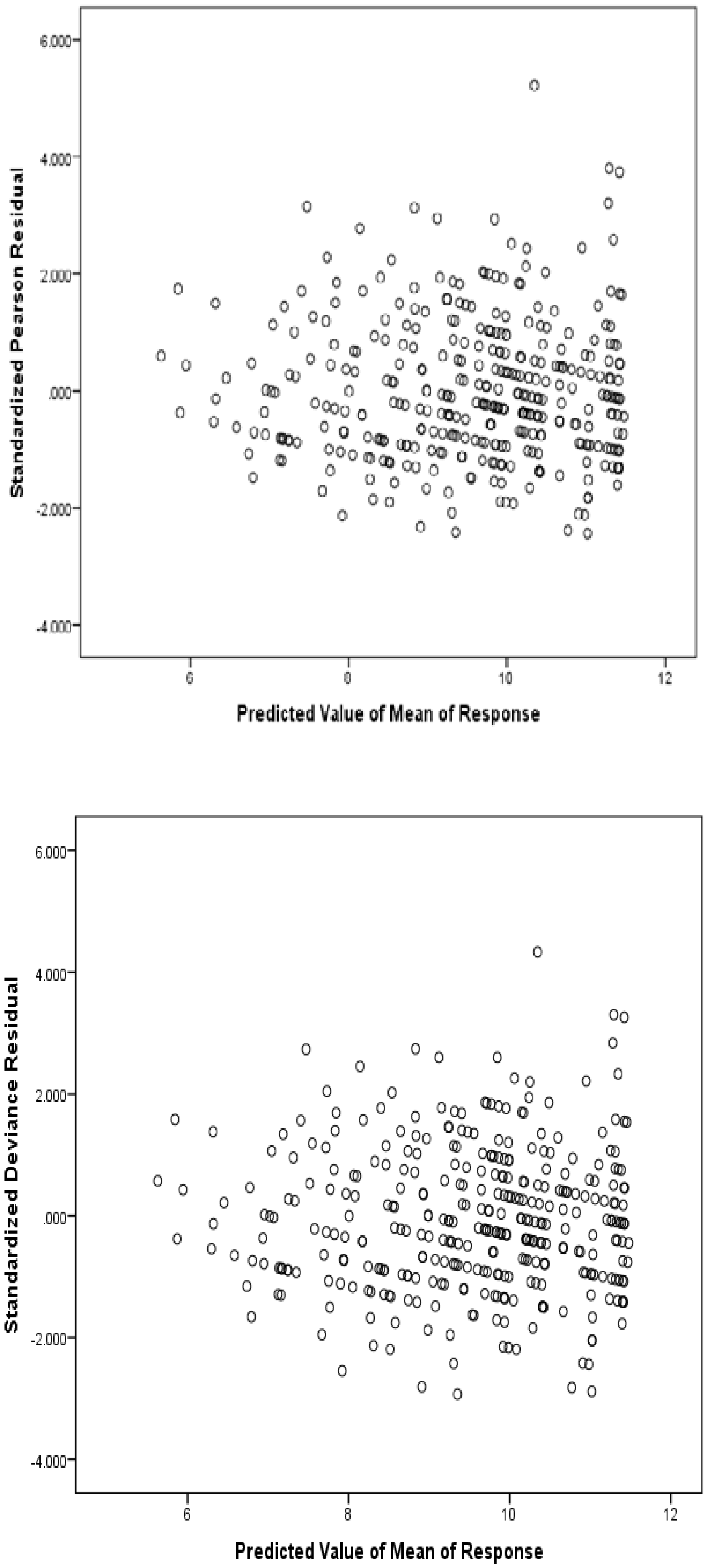


Figure 51: Children and adolescents respiratory effect model (all addresses inclusive): Model adequacy test

3.3.5.2 Autoregressive children and adolescents respiratory effect model (all addresses inclusive)

The model is as follows.

Table 89: Autoregressive children and adolescents respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.814	.1020	1.614	2.014	316.571	1	.000
[Saturday=No]	.283	.0540	.177	.389	27.357	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
[Winter=No]	-.0757	.0467	-.167	.016	2.631	1	.105
[Winter=Yes]	0[a]	.	.	.	.	.	.
NO_2_7 (AM)	-.597	.1404	-.872	-.322	18.087	1	.000
Respiratory_1	.0219	.0043	.013	.030	25.897	1	.000
Respiratory_5	.0139	.0044	.005	.023	9.959	1	.002
a. Set to zero because this parameter is redundant.							

Addition of autoregressive terms at different lags reduced the autocorrelations significantly. The model consists of significant indicator variables non-winter, non-Saturday and 1 week long arithmetic distributed lag effect of NO_2. The coefficients reveal the following relative risks and corresponding percent changes in ARI admission per unit (as indicated) increase in predictor values (or codes).

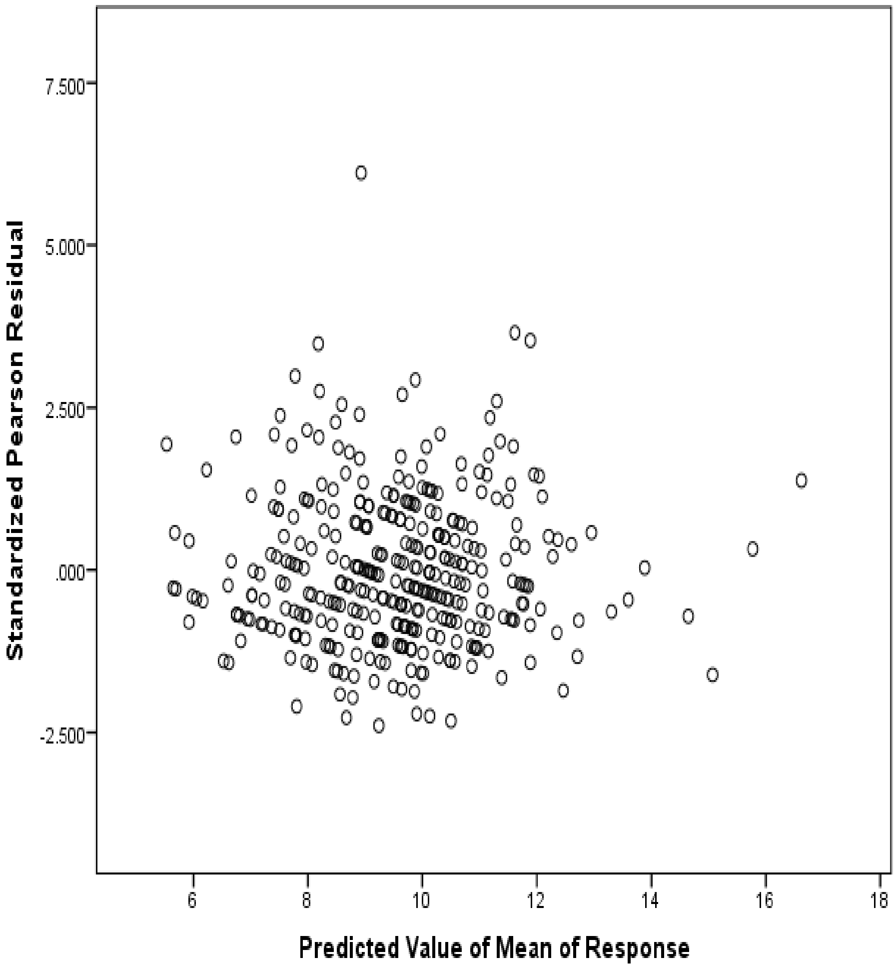
Relative risks estimates and percent increase are given below.

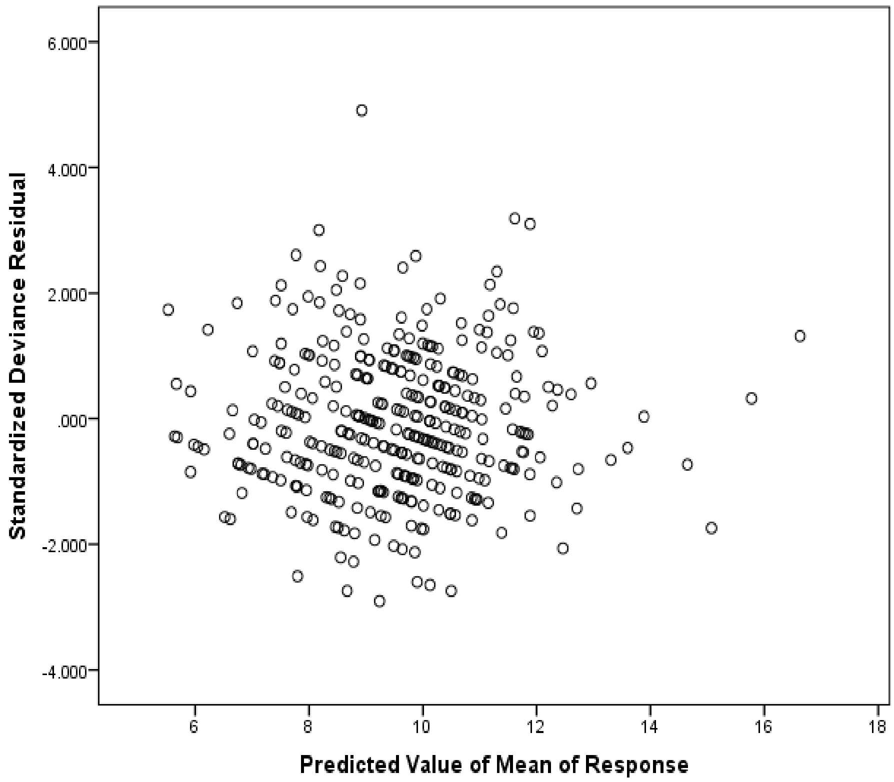
Table 90: Autoregressive children & adolescents respiratory effect model (all addresses inclusive): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
NO_2_7 (AM)	-0.5970	1	mg/m^3	0.550	-44.95
Non-Saturday*	0.283	1	-	1.327	32.71
Not Winter*	-0.0757	1	-	0.927	-7.29
*Categorical variable					

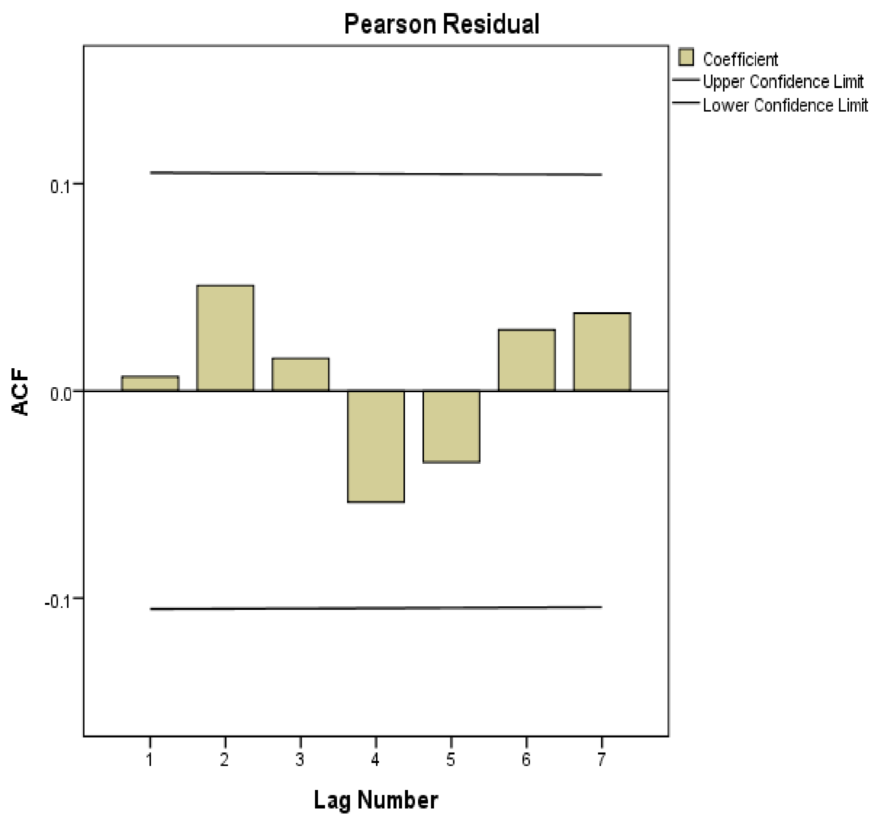
Table 91: Autoregressive children and adolescents respiratory effect model (all addresses inclusive): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=557.2 at 357 df; Residual Deviance:455.2 at 352 df Omnibus test: highly significant with log likelihood chi-square: (102 at 5 df; p <0.0001)	Good
Multicollinearity	VIfs<1.5	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No Significant autocorrelations
Normality	KS test for deviance residual with p =0.34; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	One detected but ignored





6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Deviance Residual
6
8
10
12
14
16
18
Predicted Value of Mean of Response



Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
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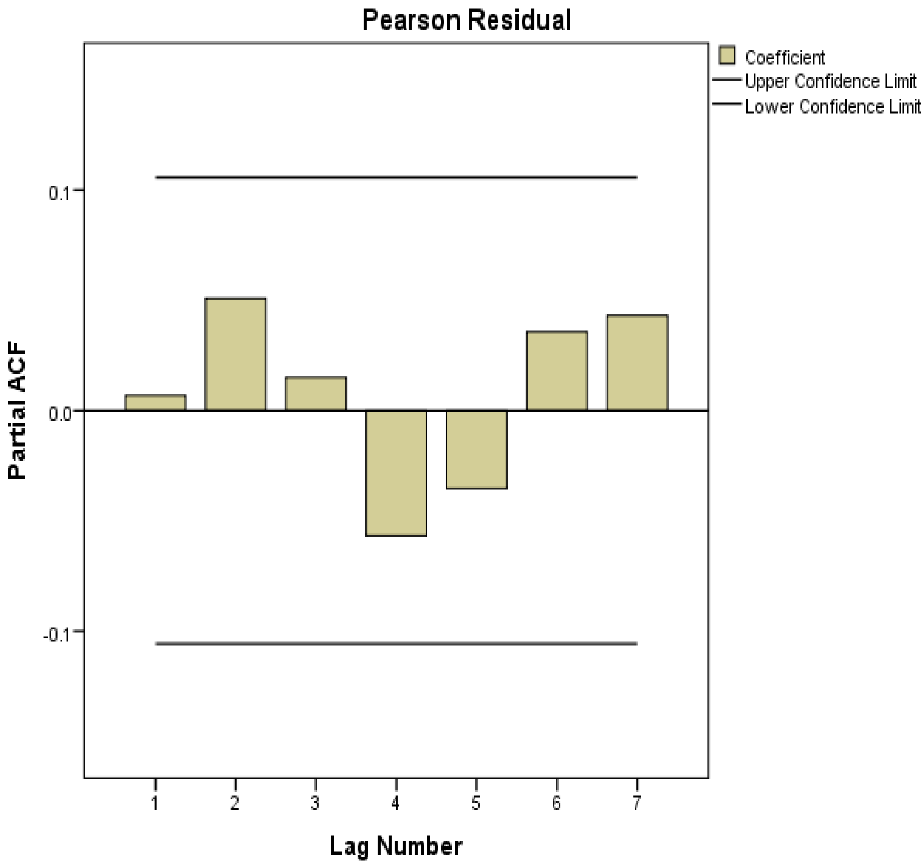
0.0
-0.1
ACF
1
2
3
4
5
6
7
Lag Number


Pearson Residual
Coefficient
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Lower Confidence Limit
Partial ACF
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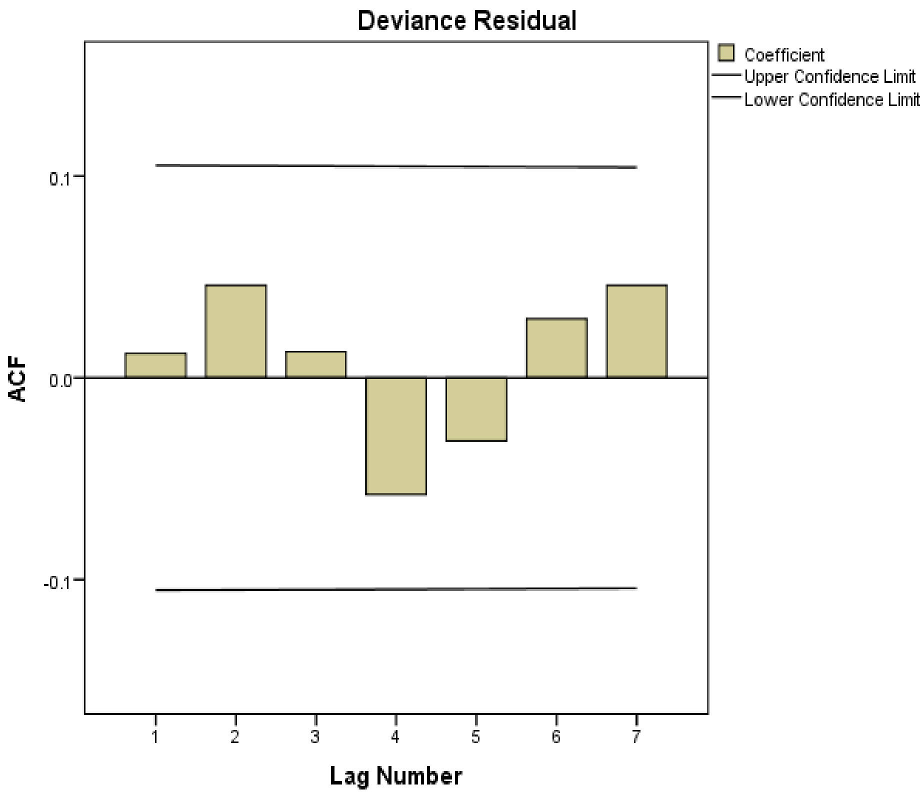
Lag Number


Deviance Residual
Coefficient
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Lower Confidence Limit
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Lag Number

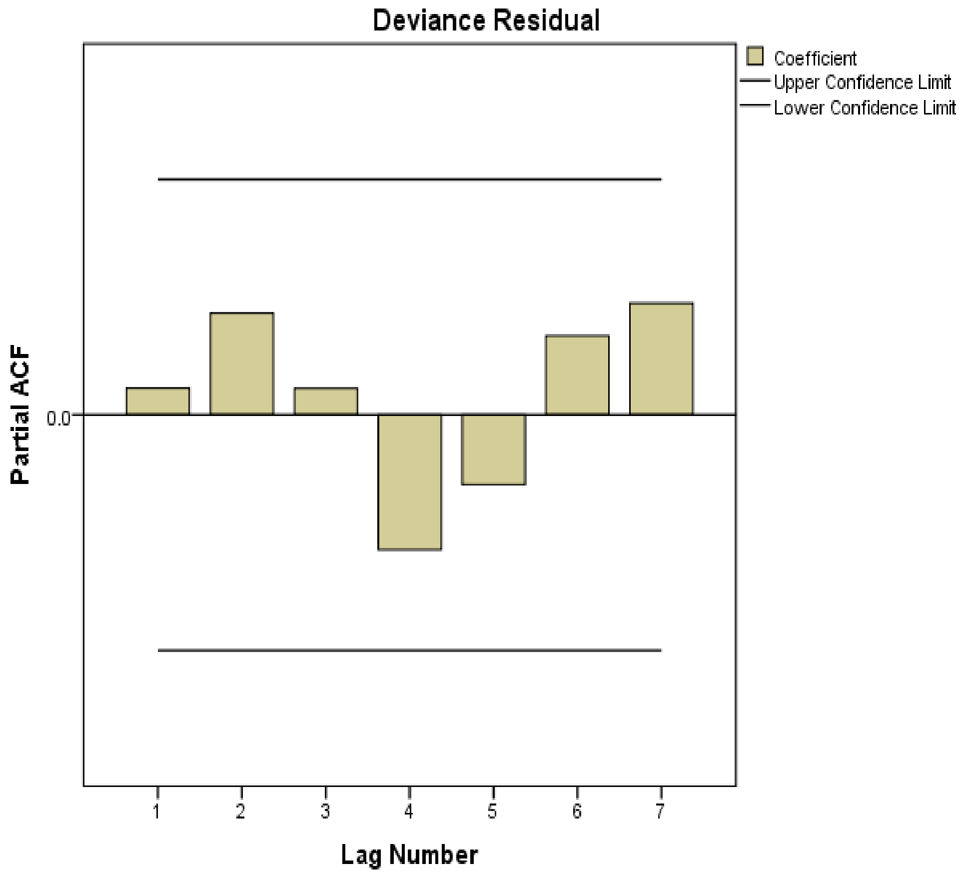


Figure 52: Autoregressive children & adolescent respiratory effect model (all addresses inclusive): Model adequacy test

3.3.5.3 Children & adolescent respiratory effect model (address Kathmandu Valley)

Table 92: Children & adolescents respiratory effect model (address Kathmandu Valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.881	.0887	1.708	2.055	450.289	1	.000
[Saturday=No]	.321	.0666	.191	.452	23.291	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
[Autumn=No]	-.150	.0634	-.274	-.025	5.579	1	.018
[Autumn=Yes]	0[a]	.	.	.	.	.	.
Rainfall_7 (AM)	-.0106	.0061	-.023	.001	3.001	1	.083
NO_2_7 (Mean)	-.8522	.1707	-1.187	-.518	24.934	1	.000
a. Set to zero because this parameter is redundant.							

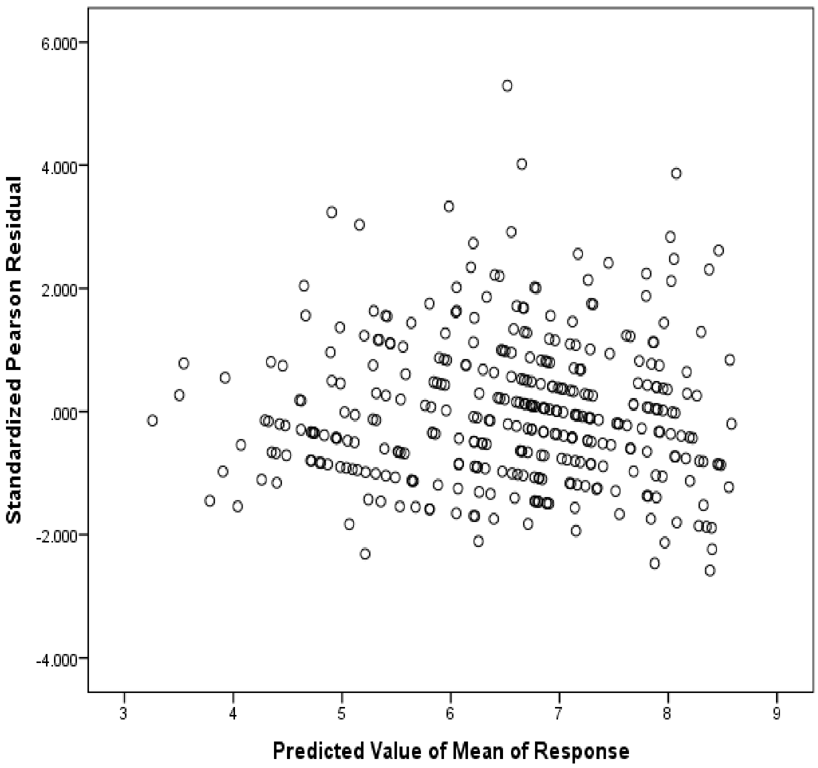
The statistical model with respiratory hospitalizations as the response variable developed for children and the adolescent population (ages ≤19) and address in Kathmandu Valley showed that indicator variables like non-Autumn and non-Saturday are found to be statistically significant. Additionally, a weeklong arithmetic distributed lag effect of NO_2 is also statistically significant. The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes). Relative risks estimates and percent increases are given below.

Table 93: Children and adolescents respiratory effect model (address Kathmandu Valley): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
NO_2_7 (mean)	-0.8522	1	mg/m^3	0.426	-57.35
Rainfall_7 (AM)	-0.0106		mm	0.989	-1.05
Non-Saturdays*	0.321	1	-	1.379	37.85
Not Autumn*	-0.15	1	-	0.861	-13.93
*Categorical variable					

Table 94: Children and adolescents respiratory effect model (address Kathmandu valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=562.4 at 357 df; Residual Deviance:488.9 at 353 df Omnibus test: highly significant with log likelihood chi-square: (73.5 at 4 df; p <0.0001)	Good
Multicollinearity	VIfs<2	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelations at 1 and 5 lags
Normality	KS test for deviance residual with p =0.67; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	One detected but ignored



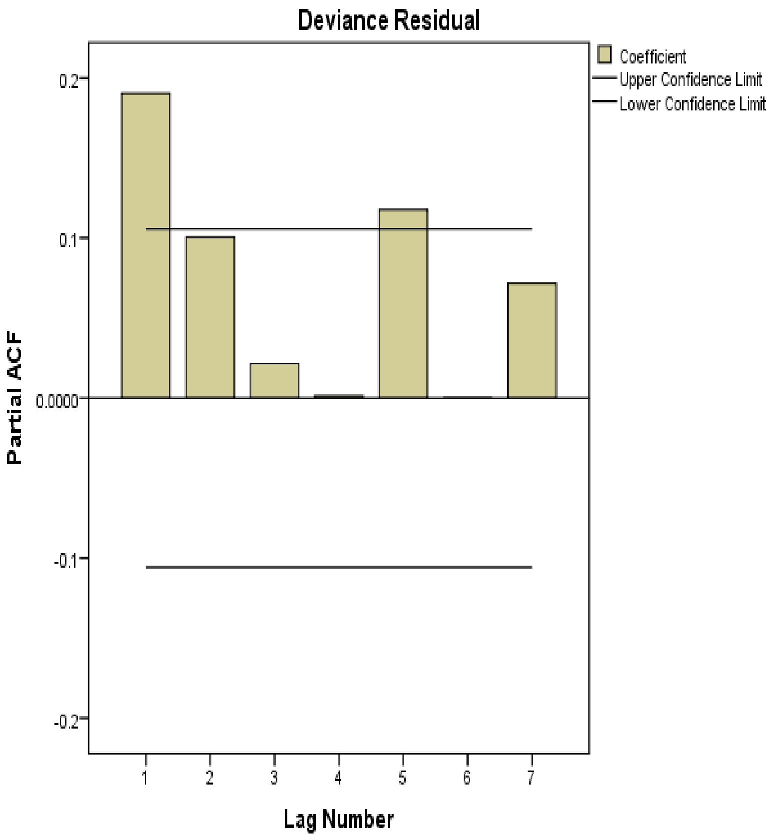


Figure 53: Children and adolescents respiratory effect model (address Kathmandu Valley): Model adequacy test

3.3.5.4 Autoregressive children and adolescents respiratory effect model (address Kathmandu Valley)

The model is as follows.

Table 95: Autoregressive children and adolescents respiratory effect model (address Kathmandu valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.478	.1193	1.244	1.712	153.498	1	.000
[Saturday=No]	.361	.0670	.229	.492	28.969	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
[Autumn=No]	-.104	.0649	-.231	.023	2.575	1	.109
[Autumn= Yes]	0[a]	.	.	.	.	.	.
NO_2_7 (Mean)	-.6602	.1747	-1.003	-.318	14.279	1	.000
Rainfall_7(AM)	-.0097	.0062	-.022	.002	2.492	1	.114
Respiratory_1	.0234	.0064	.011	.036	13.620	1	.000
Respiratory_5	.0215	.0065	.009	.034	11.054	1	.001
a. Set to zero because this parameter is redundant.							

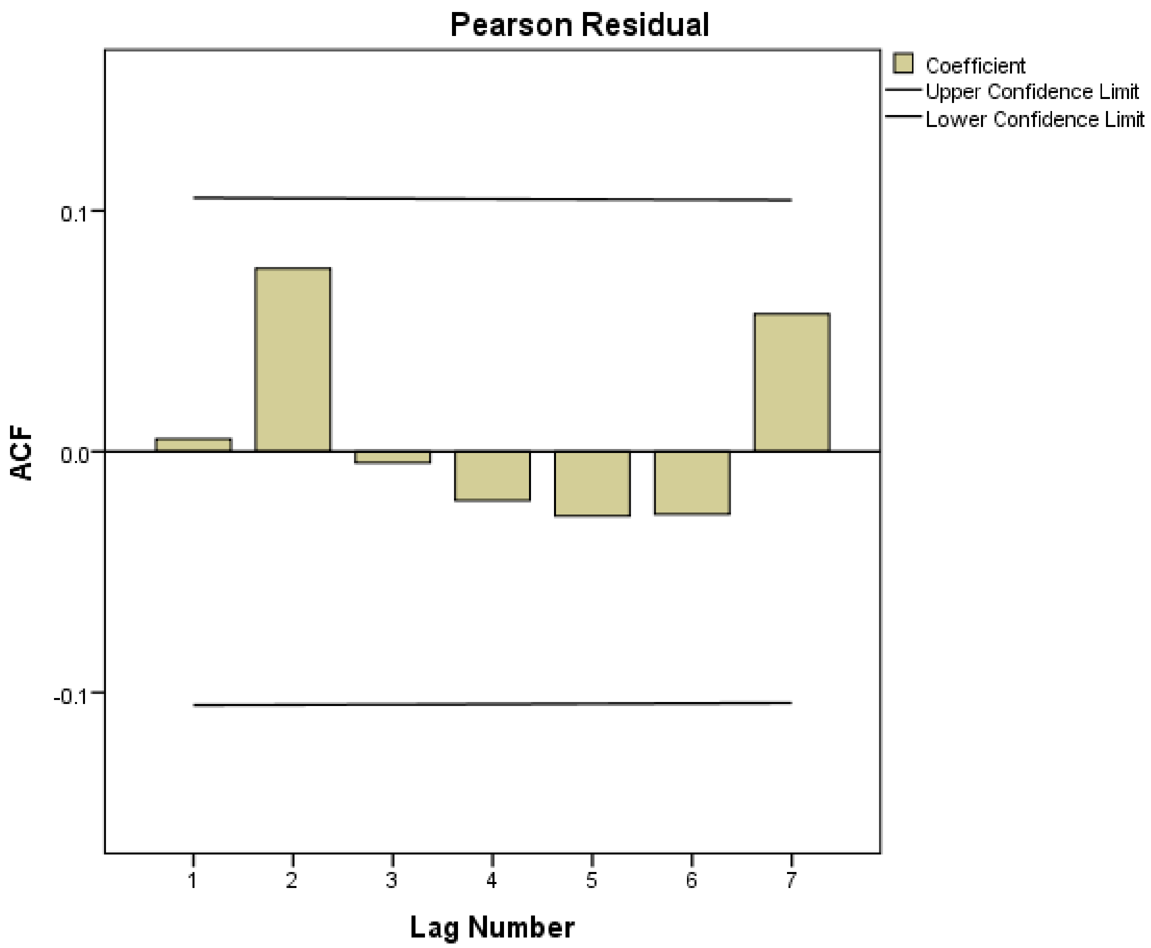
Addition of autoregressive terms at different lags reduced autocorrelations significantly. The autocorrelation-corrected model consists of significant indicator variables, namely non-Autumn and non-Saturday effects, and a week arithmetic distributed lag effect of rainfall. The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

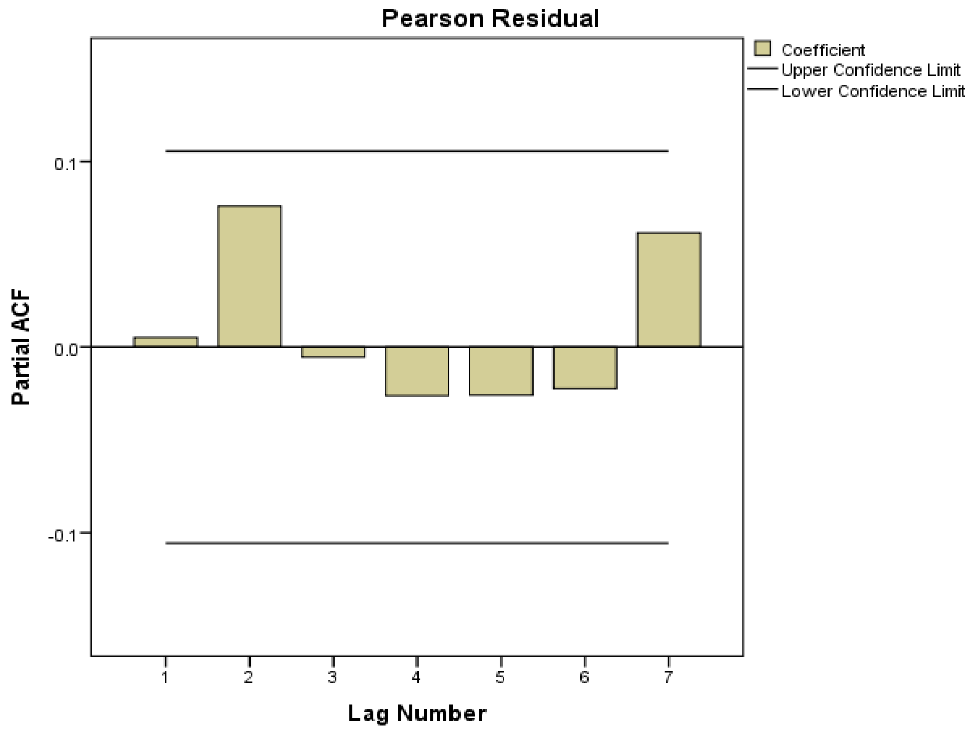
Table 96: Autoregressive children and adolescents respiratory effect model (address Kathmandu valley): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
NO_2_7 (mean)	-0.6602	1	mg/m^3	0.517	-48.33
Rainfall_7 (AM)	-0.0097	1	mm	0.990	-0.97
Non-Saturdays*	0.361	1	-	1.435	43.48
Not Autumn*	-0.104	1	-	0.901	-9.88
*Categorical variable					

Table 97: Autoregressive children and adolescents respiratory effect model (address Kathmandu Valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=562.4 at 357 df; Residual Deviance:462.2 at 351 df Omnibus test: highly significant with log likelihood chi-square: (100.2 at 6 df; p <0.0001)	Good
Multicollinearity	VIfs<2	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.66; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	One detected but ignored




Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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0.0
-0.1
1
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3
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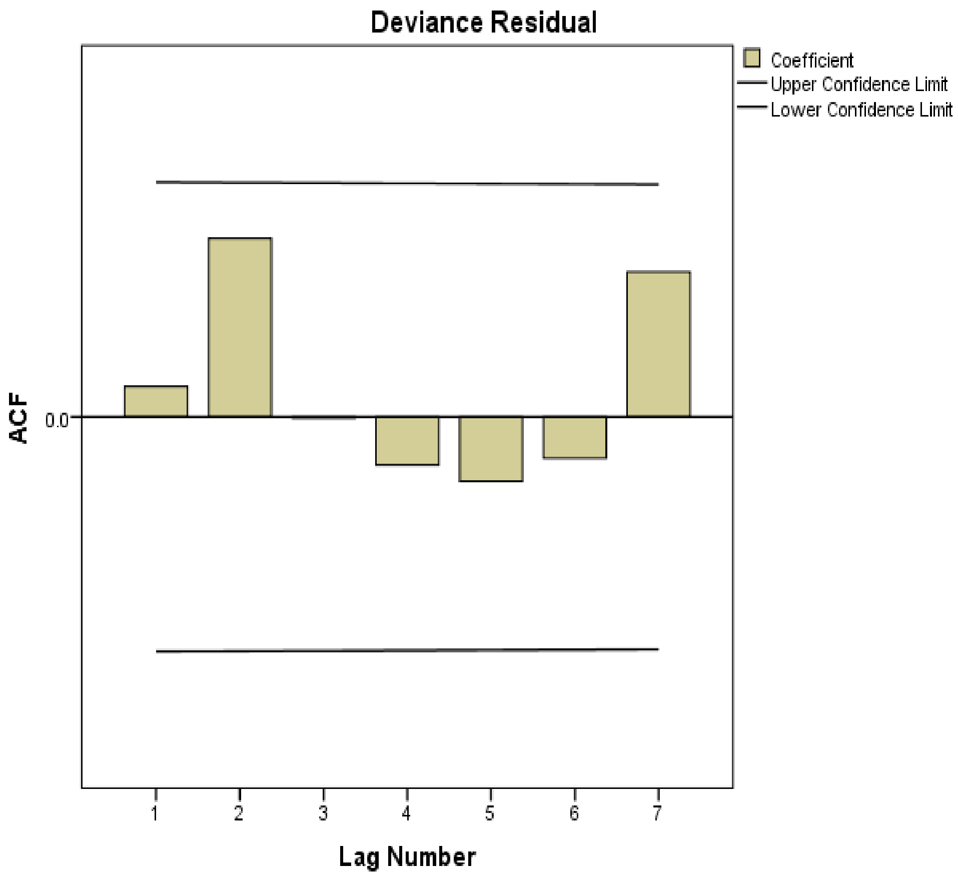
7
Lag Number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Coefficient
Upper Confidence Limit
Lower Confidence Limit
ACF
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2
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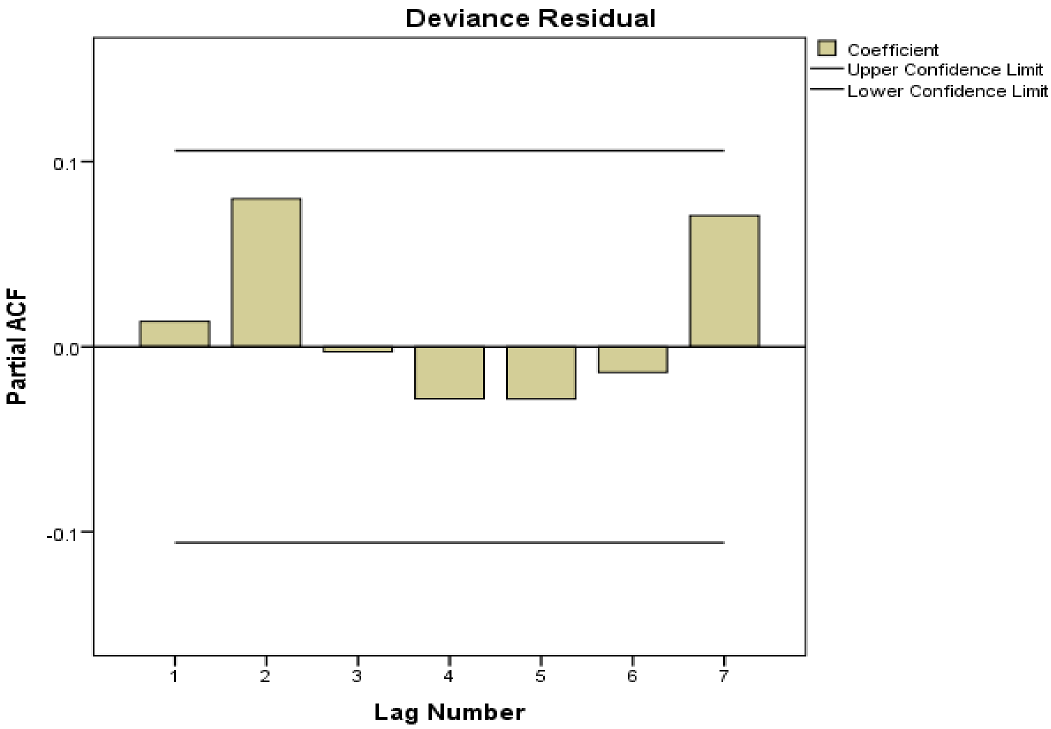
Lag Number


Deviance Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
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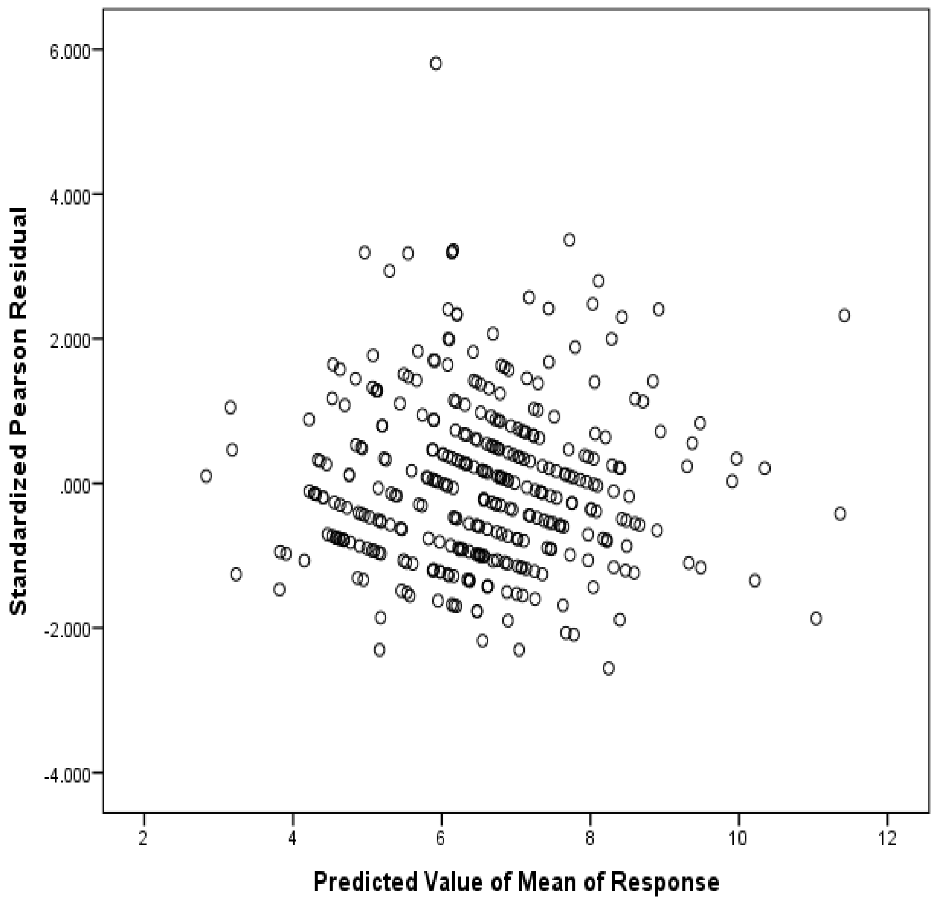
0.0
-0.1
Partial ACF
1
2
3
4
5
6
7
Lag Number


6.000
4.000
2.000
.000
-2.000
-4.000
Standardized Pearson Residual
2
4
6
8
10
12
Predicted Value of Mean of Response

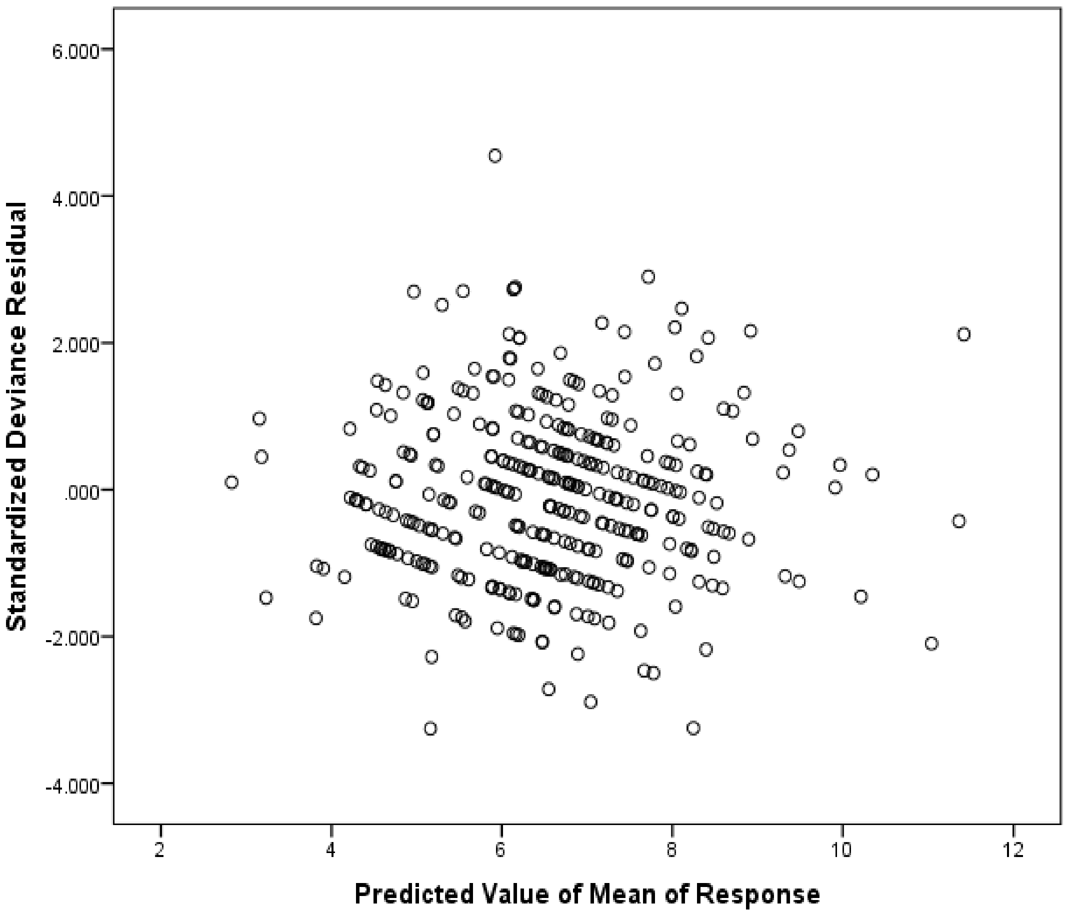


Figure 54: Autoregressive children and adolescents respiratory effect model (address Kathmandu valley): Model adequacy test

3.3.5.4 Comparative assessment between children and adolescents respiratory effect GLMs

Table 98: Comparative assessment between children and adolescents respiratory effect GLMs

Particular	Respiratory		Respiratory (Autoregressive)		Respiratory KTM		Respiratory KTM (Autoregressive)	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	X	_	X	_	X	_	X	_
CO	X	_	X	_	X	_	X	_
NO_2	-52.05 (0.00)	7 day AM lag	-44.95 (0.00)	7 day AM lag	-57.35 (0.00)	7 day mean	-48.33	7 day mean
Not Spring	X	_	X	_	X	_	X	_
Not Autumn	-8.58 (0.04)	_	X	_	-13.93 (<0.02)	_	-9.88 (0.01)	_
Not Winter	-11.2 (<0.01)	_	-7.29 (0.01)	_	X	_	X	_
Rainfall	X	_	X	_	-1.05 (0.08)	7 day AM lag	-0.97 (0.1)	7 day AM lag
Non-Saturday	28.0 (0.00)	-	32.7 (0.00)	-	37.9 (0.00)	-	43.5 (0.00)	
Autoregressive lag effects	-	-		1, 5 (+)	-	-		1, 5 (+)

Note: Temperature and relative humidity are either insignificant or associated with VIFs.

Interpretation / Assessment

$PM_{2.5}$ and CO are found to be statistically insignificant for respiratory hospitalizations for the sub-population comprising children and adolescents aged 19 and less, which is rather a contrasting result to that of the other models developed. NO_2 is found to be negatively associated with respiratory hospitalizations with a 7 day lag effect. Instead of temperature, seasonal indicator variables are found to be more significant for respiratory hospitalizations in this sub-population, another contrasting result. When temperature and relative humidity are included the models either suffer from the problem of multicollinearity or the variables become statistically insignificant. Rainfall is found to be negatively associated with hospitalizations when only Kathmandu residents are considered, with around 1% decrease in respiratory hospitalizations per 1% increase in rainfall. The risk of hospitalization is greater on working days compared to holidays (i.e. Saturdays) for all four developed respiratory effect models, with around 28-44% increase in hospitalizations for non-Saturdays. Slight positive autocorrelations are observed for the models at 1 and 5 day lags, which are corrected in the autoregressive GLMs.

3.3.6 Aged respiratory effect models

Separate models were generated for aged population (50 and above).

3.3.6.1 Aged (≥50 years) respiratory effect model (all addresses inclusive)

The model is as follows.

Table 99: Aged (≥50 years) respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.670	.1391	3.398	3.943	696.029	1	.000
[Saturday=No]	.415	.0426	.331	.498	94.993	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
PM_0	.0012	.0005	.000	.002	7.055	1	.008
NO_2_2 (Mean)	.0917	.0548	-.016	.199	2.801	1	.094
Relative Humidity_2 (Mean)	-.0295	.0030	-.035	-.024	93.641	1	.000
Rainfall_2 (Mean)	-.0060	.0026	-.011	-.001	5.391	1	.020
a. Set to zero because this parameter is redundant.							

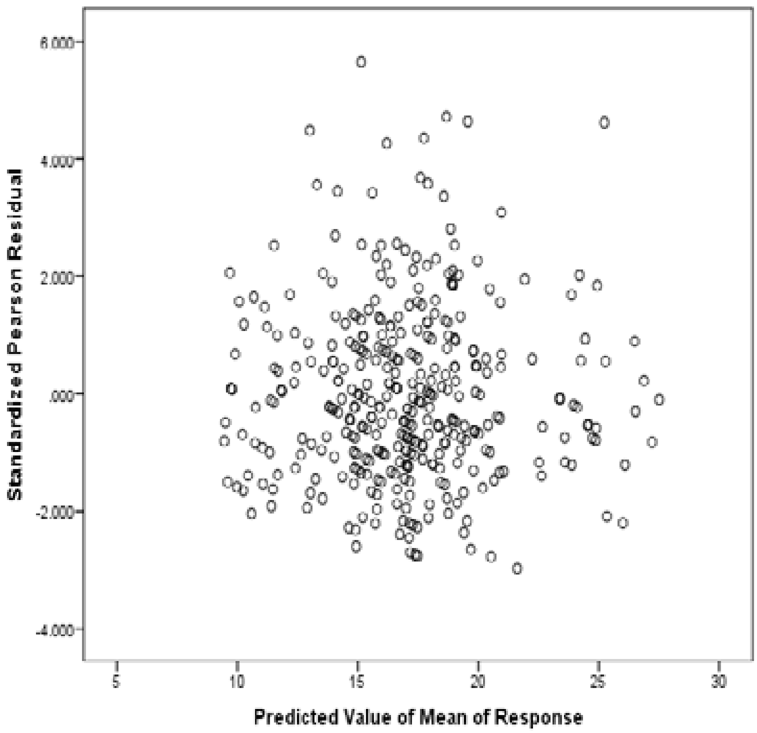
The statistical model with respiratory hospitalizations as the response variable developed for the elderly population (ages ≥50) showed statistically significant effects for same day $PM_{2.5}$ (positive), 2 day mean of NO_2 (positive), relative humidity (negative), rainfall (negative) and non-Saturday (positive). The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

Table 100: Aged (≥50 years) respiratory effect model (all addresses inclusive): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0012	10	µg/m^3	1.012	1.21
NO_2_2 (mean)	0.0917	1	mg/m^3	1.096	9.60
Relative Humidity_2 (Mean)	-0.0295	1	%	0.971	-2.91
Rainfall_2 (Mean)	-0.006	1	mm	0.994	-0.60
Non-Saturdays*	0.415	1	-	1.514	51.44
*Categorical variable					

Table 101: Aged (≥50 years) respiratory effect model (all addresses inclusive): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=1025.5 at 363 df; Residual Deviance:759.8 at 358 df Omnibus test: highly significant with log likelihood chi-square: (265.7 at 5 df; p <0.0001)	Good
Multicollinearity	VIfs<2	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slight significant autocorrelations at 1 and 2 lags
Normality	KS test for deviance residual with p =0.46; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	One detected but ignored



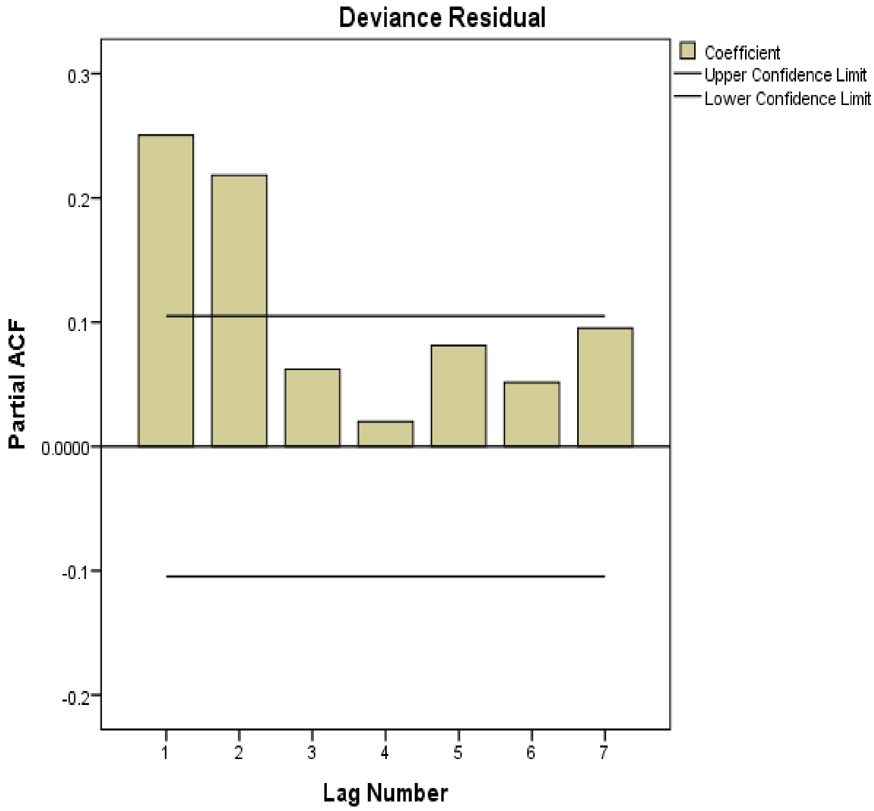


Figure 55: Aged respiratory effect model (all addresses inclusive): Model adequacy test

3.3.6.2 Autoregressive aged respiratory effect model (all addresses inclusive)

The model is as follows.

Table 102: Autoregressive aged respiratory effect model (all addresses inclusive)

Parameter Estimates							
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	2.722	.1743	2.381	3.064	244.059	1	.000
[Saturday=No]	.422	.0426	.339	.506	98.344	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
PM_0	.0008	.0005	-8.238E-005	.002	3.179	1	.075
NO_2_2 (Mean)	.0723	.0545	-.034	.179	1.761	1	.184
Relative Humidity_2 (Mean)	-.0164	.0034	-.023	-.010	23.487	1	.000
Rainfall_2 (Mean)	-.0041	.0026	-.009	.001	2.459	1	.117
Respiratory_1	.0090	.0019	.005	.013	22.431	1	.000
Respiratory_2	.0135	.0019	.010	.017	49.120	1	.000
a. Set to zero because this parameter is redundant.							

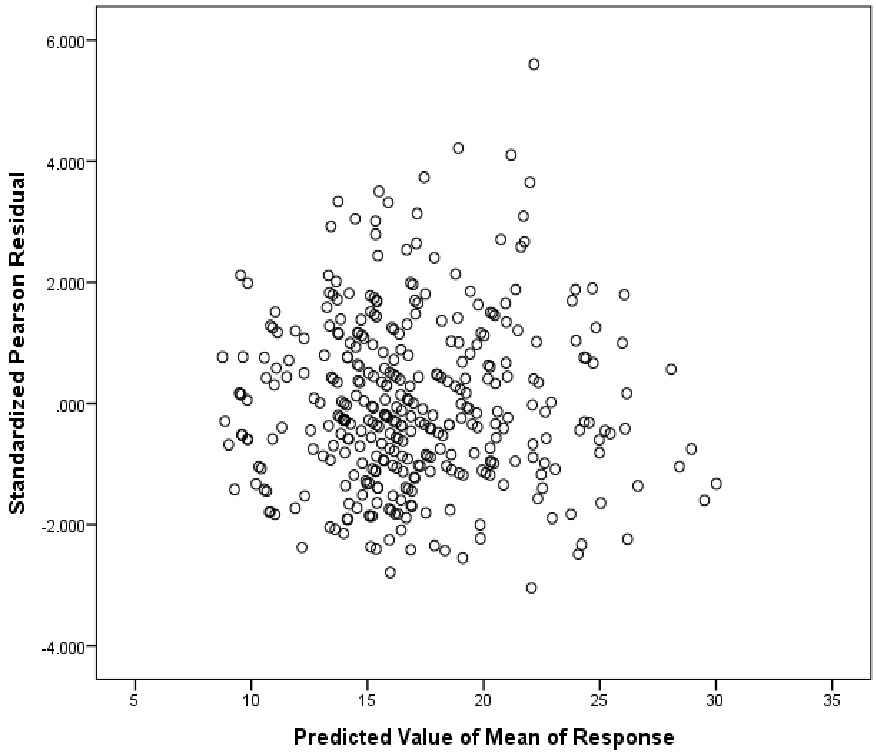
Addition of autoregressive terms at different lags (1 and 2 days) reduced the autocorrelations significantly. The autocorrelation-corrected model consists of statistically significant effects for same day $PM_{2.5}$ (positive), 2 day mean of NO_2 (positive), relative humidity (negative), rainfall (negative) and non-Saturday (positive). The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes).

Table 103: Autoregressive aged respiratory effect model (all addresses inclusive): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0008	10	µg/m³	1.008	0.80
NO_2_2 (mean)	0.0723	1	mg/m³	1.075	7.50
Relative Humidity_2 (Mean)	-0.0164	1	%	0.984	-1.63
Rainfall_2 (Mean)	-0.0041	1	mm	0.996	-0.41
Non-Saturdays*	0.422	1	-	1.525	52.50
*Categorical variable					

Table 104: Autoregressive aged respiratory effect model (all addresses inclusive): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=1023.5 at 362 df; Residual Deviance:672.7 at 355 df Omnibus test: highly significant with log likelihood chi-square: (350.9 at 7 df; p <0.0001)	Good
Multicollinearity	VIfs<1.5	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Just significant autocorrelation at 7 lag (ignored)
Normality	KS test for deviance residual with p =0.48; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	One detected but ignored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4.000
2.000
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-2.000
-4.000
Standardized Pearson Residual
5
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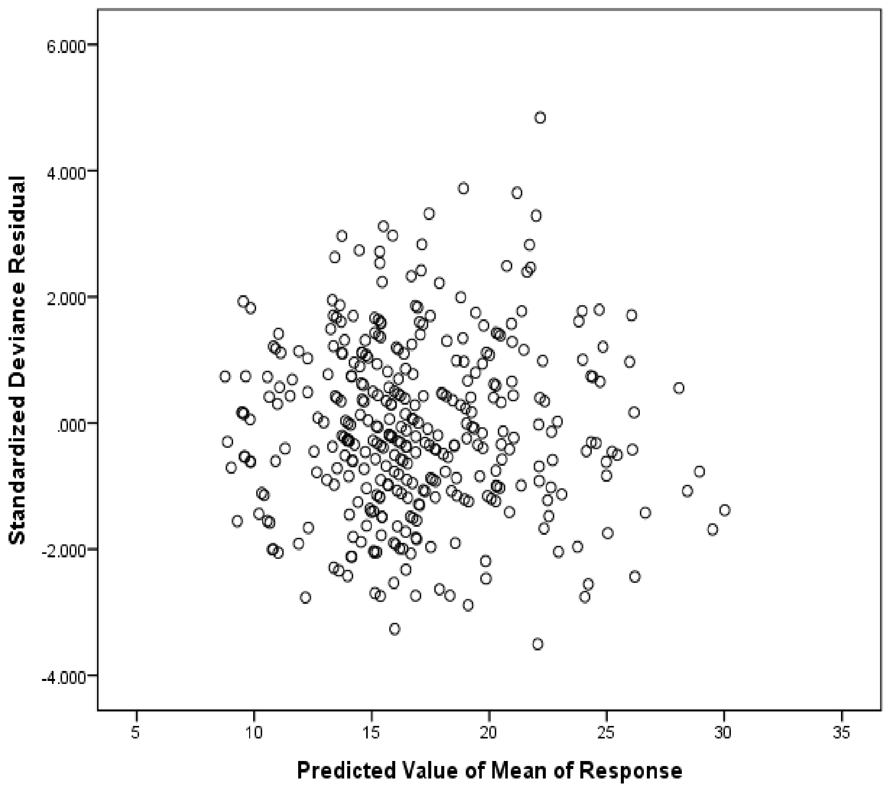
30
35
Predicted Value of Mean of Response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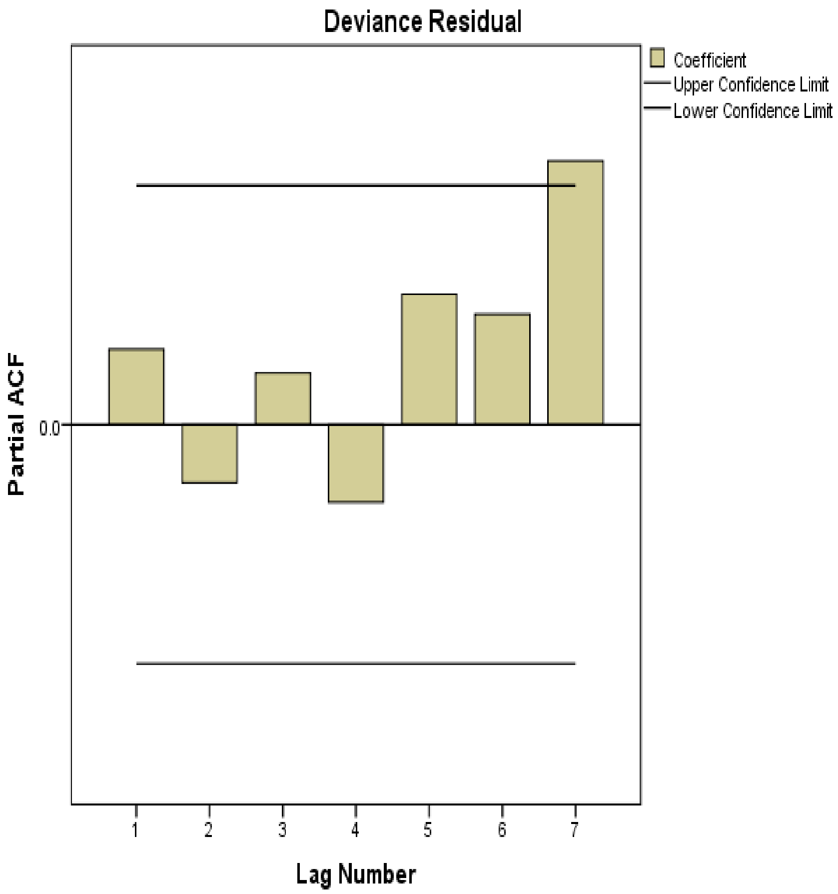
Predicted Value of Mean of Response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Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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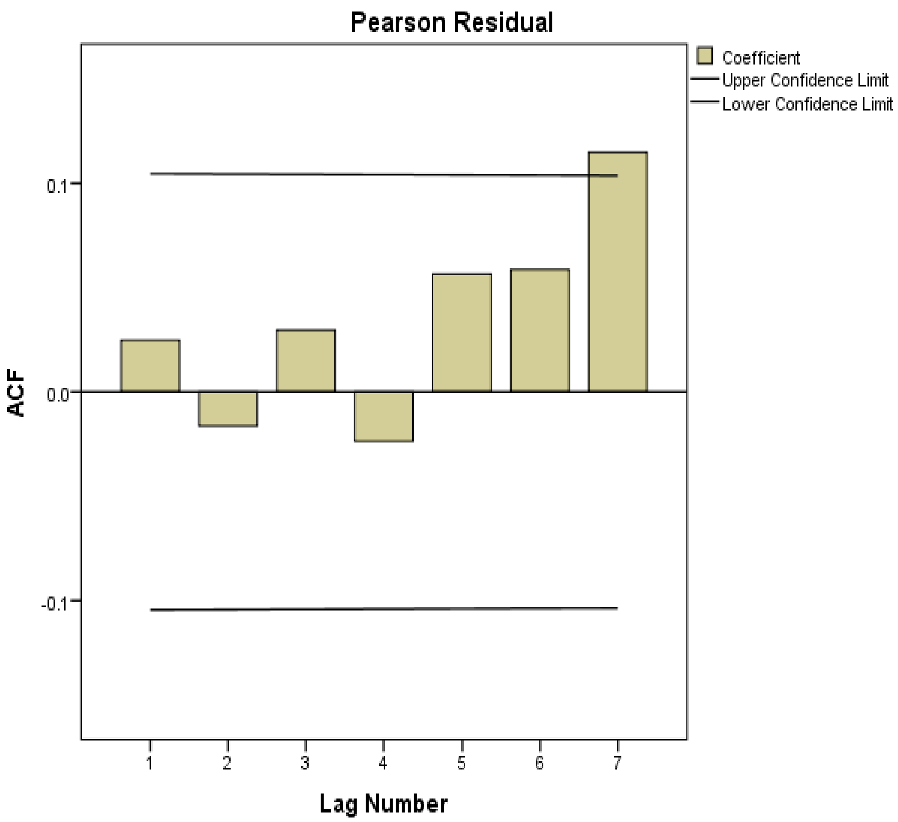
Lag Number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Coefficient
Upper Confidence Limit
Lower Confidence Limit
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Lag Number

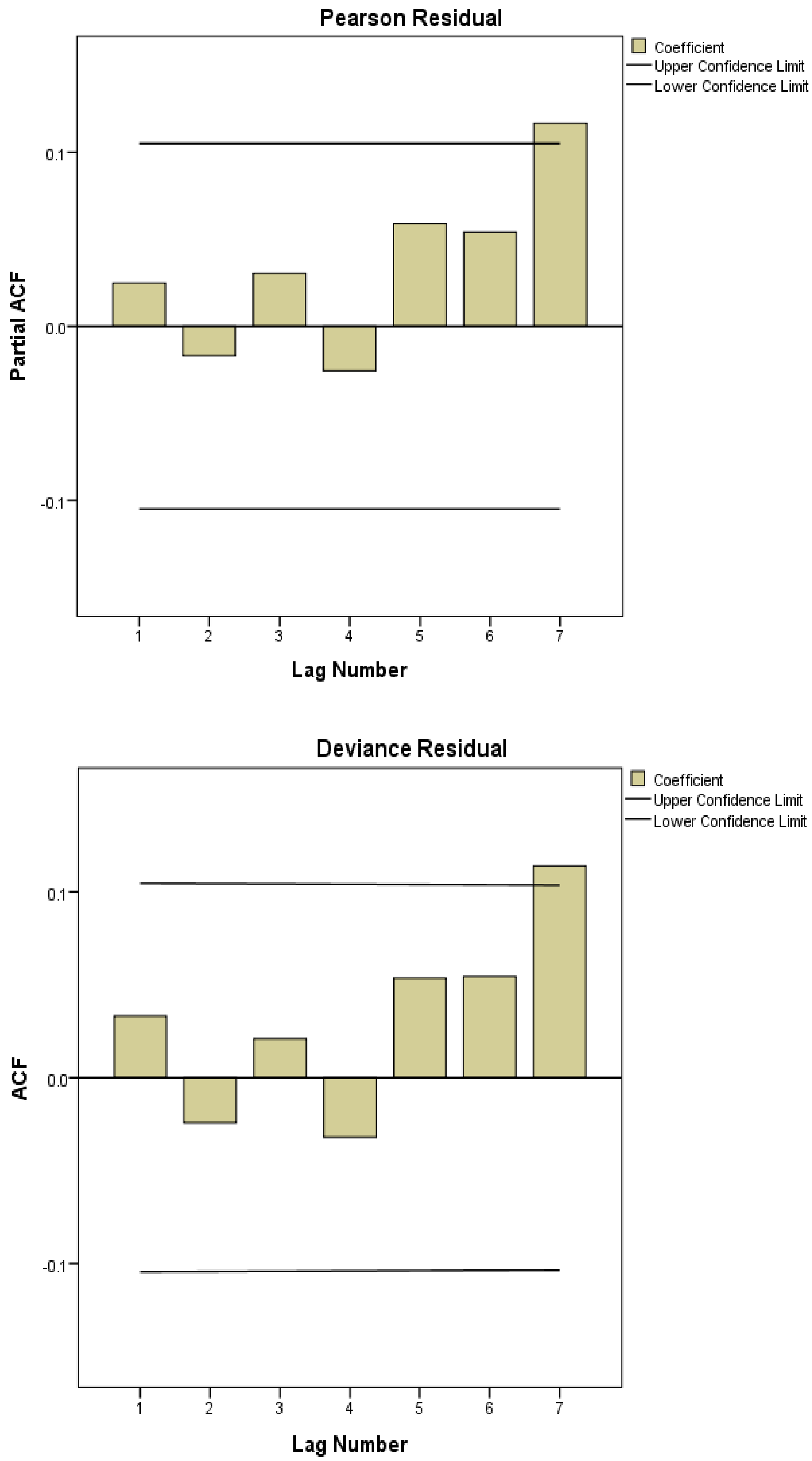


Figure 56: Autoregressive aged respiratory effect model (all addresses inclusive): Model adequacy test

3.3.6.3 Aged respiratory effect model (address Kathmandu valley)

The model is as follows.

Table 105: Aged respiratory effect model (address Kathmandu valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.098	.2442	2.620	3.577	160.956	1	.000
[Saturday=No]	.383	.0526	.280	.486	52.917	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0029	.0007	.001	.004	15.914	1	.000
CO_0	.0571	.0308	-.003	.117	3.450	1	.063
Temperature_0	.0073	.0041	-.001	.015	3.182	1	.074
Relative Humidity_0	-.0314	.0039	-.039	-.024	65.102	1	.000
Rainfall_2 (Mean)	-.0064	.0033	-.013	-1.463E-005	3.859	1	.049
a. Set to zero because this parameter is redundant.							

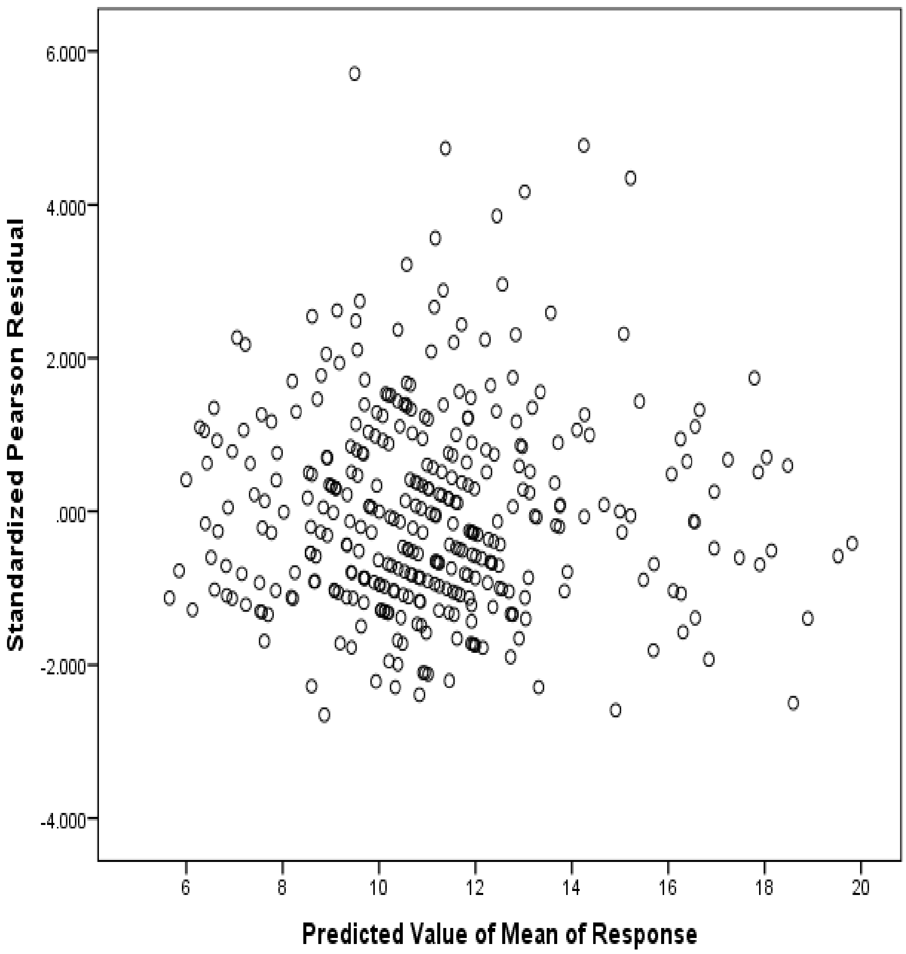
The statistical model with respiratory hospitalizations as the response variable developed for the elderly population (ages ≥50) and addresses in Kathmandu Valley showed statistically significant effects for same day $PM_{2.5}$ (positive), CO (positive), temperature (positive) and relative humidity (negative). Additionally, 2 day mean effect of rainfall (negative) and non-Saturday (positive) are found to be statistically significant. The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

Table 106: Aged respiratory effect model (address Kathmandu valley): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0029	10	µg/m³	1.029	2.94
CO_0	0.0571	1	mg/m³	1.059	5.88
Temperature_0	0.0073	1	⁰c	1.007	0.73
Relative Humidity_0	-0.0314	1	%	0.969	-3.09
Rainfall_2 (Mean)	-0.0064	1	mm	0.994	-0.64
Non-Saturdays*	0.383	1	-	1.467	46.67
*Categorical variable					

Table 107: Aged respiratory effect model (address Kathmandu valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=818 at 363 df; Residual Deviance:601.6 at 357 df Omnibus test: highly significant with log likelihood chi-square: (216.3 at 6 df; p <0.0001)	Good
Multicollinearity-	VIfs<2.6	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	Slightly significant autocorrelation at 1 and 2 lags
Normality	KS test for deviance residual with p =0.45; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	One detected but ignored



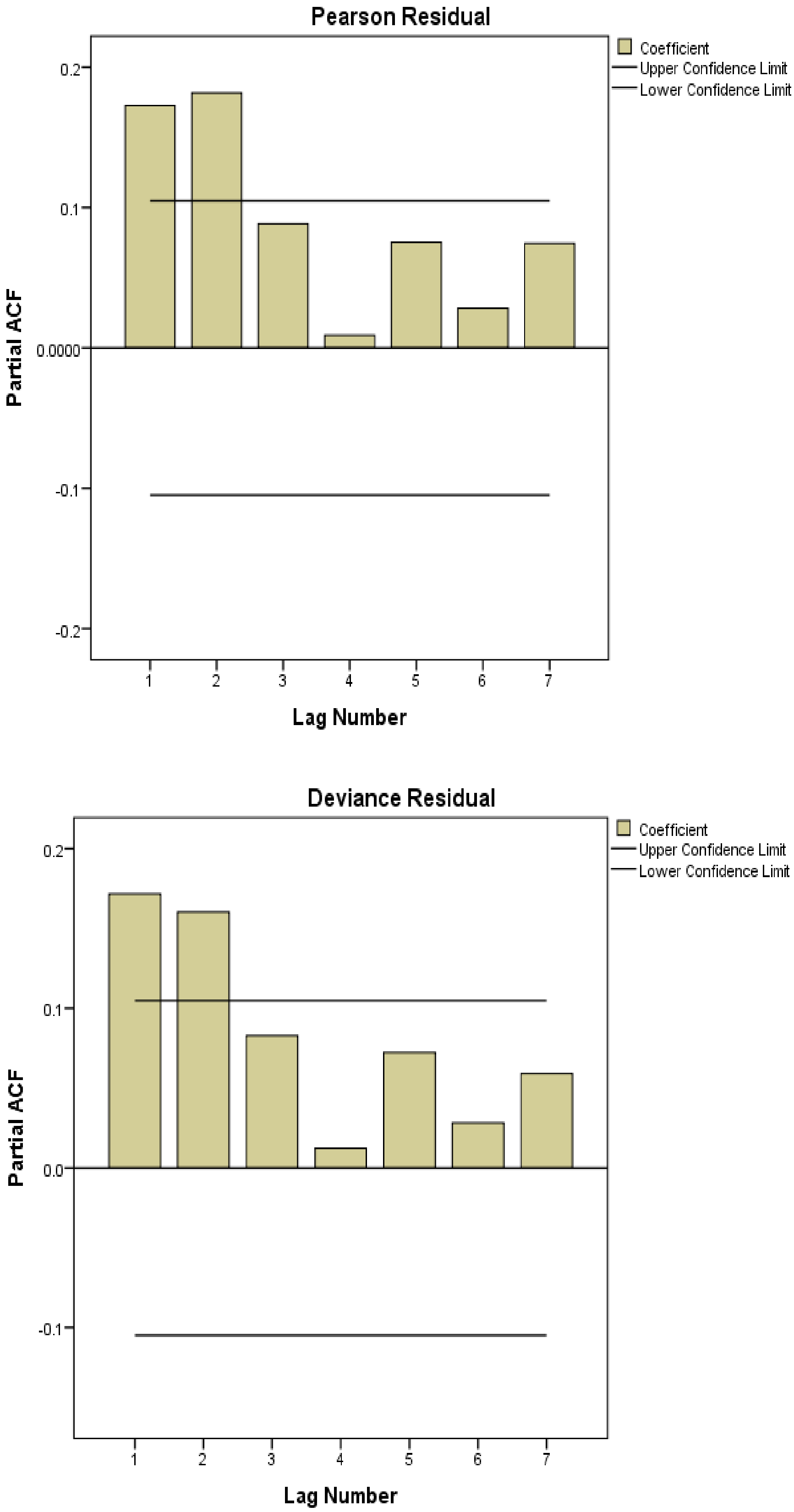


Figure 57 : Aged respiratory effect model (address Kathmandu valley): Model adequacy test

3.3.6.4 Autoregressive aged respiratory effect model (address Kathmandu valley)

The model is as follows.

Table 108: Autoregressive aged respiratory effect model (address Kathmandu valley)

Parameter Estimates							
Parameter	β	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	2.644	.2105	2.232	3.057	157.791	1	.000
[Saturday=No]	.377	.0526	.274	.480	51.399	1	.000
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_0	.0018	.0005	.001	.003	14.190	1	.000
CO_0	.0567	.0309	-.004	.117	3.372	1	.066
Relative Humidity_0	-.0232	.0041	-.031	-.015	32.390	1	.000
Respiratory_1	.0097	.0033	.003	.016	8.867	1	.003
Respiratory_2	.0163	.0033	.010	.023	25.201	1	.000
a. Set to zero because this parameter is redundant.							

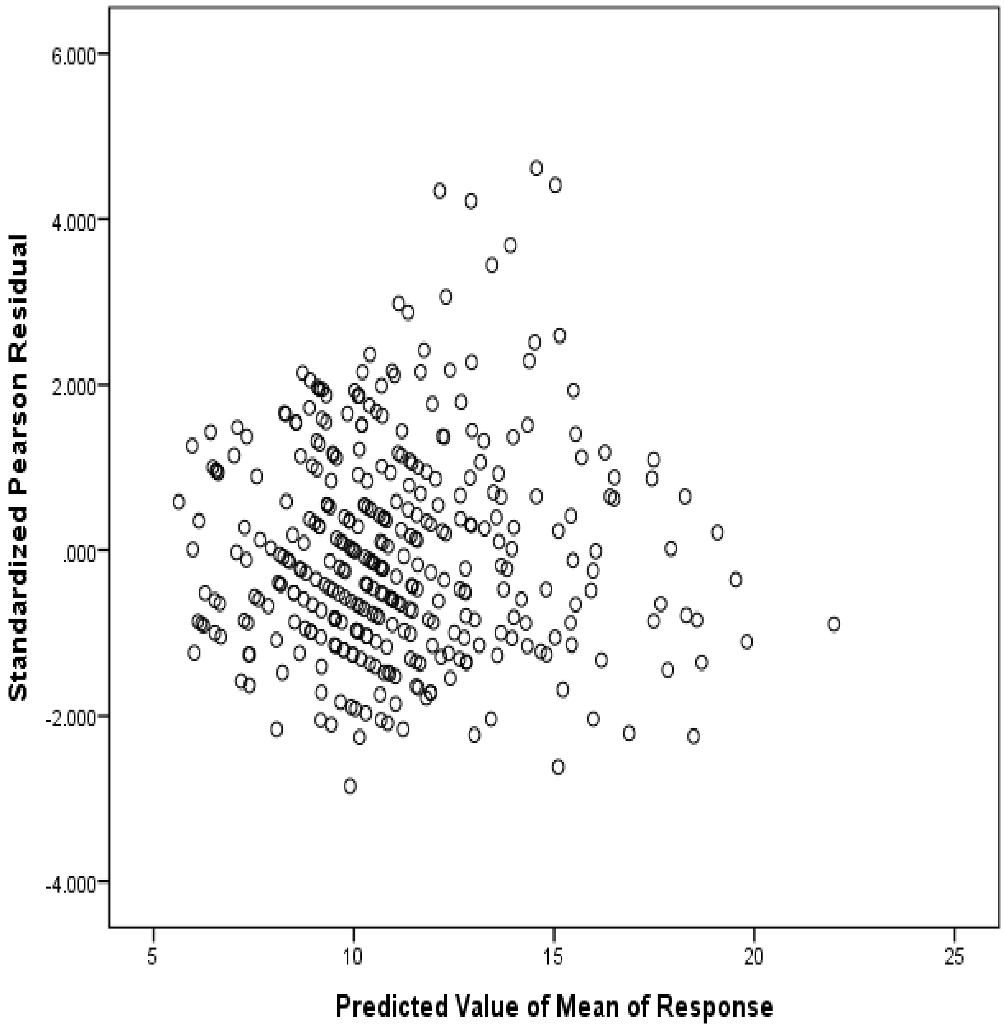
Addition of autoregressive terms at different lags (1 and 2 days) reduced autocorrelations significantly. The autocorrelation-corrected model consists of statistically significant effects of same day of $PM_{2.5}$ (positive), CO (positive) and relative humidity (negative), and non-Saturday (positive). The coefficients reveal the following relative risks and corresponding percent changes in respiratory hospitalizations per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

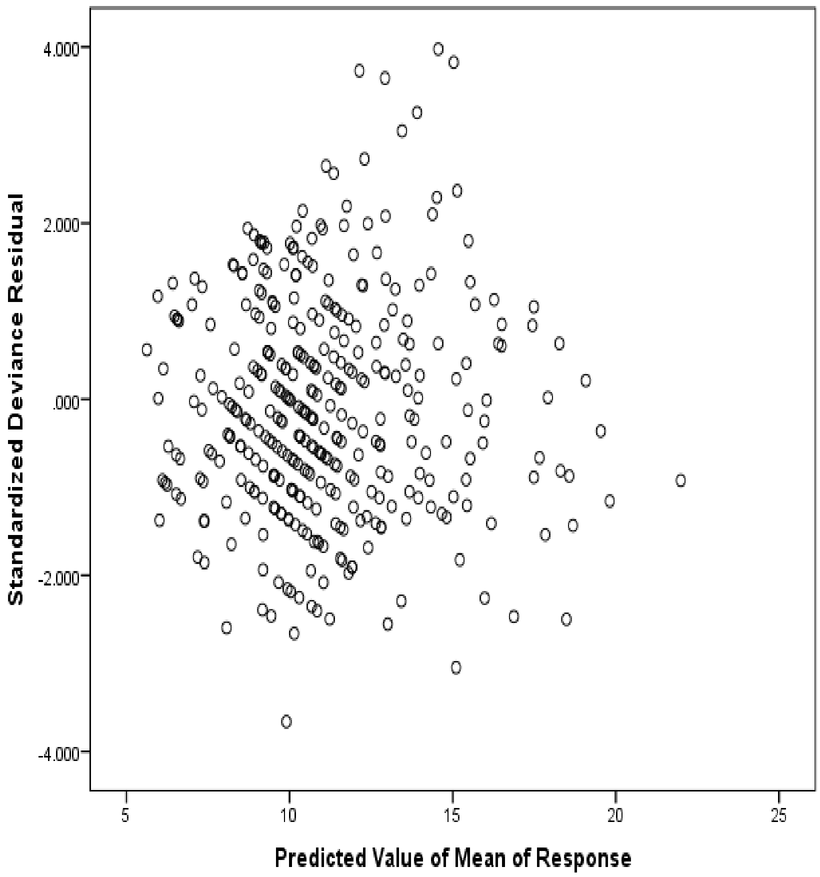
Table 109: Autoregressive aged respiratory effect model (address Kathmandu valley): Relative risks

Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_0	0.0018	10	μg/m^3	1.018	1.82
CO_0	0.0567	1	mg/m^3	1.058	5.83
Relative Humidity_0	-0.0232	1	%	0.977	-2.29
Non-Saturdays*	0.377	1	-	1.458	45.79
*Categorical variable					

Table 110: Autoregressive aged respiratory effect model (address Kathmandu valley): Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=814.4 at 362 df; Residual Deviance:568 at 356 df Omnibus test: highly significant with log likelihood chi-square: (246.4 at 6 df; p <0.0001)	Good
Multicollinearity	VIfs<1.4	No multicollinearity
Heteroscadasticity	Scatter plots between residuals versus mean predicted values	Constant variance
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.31; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatter plots between residuals versus mean predicted values	Few detected but ignored




4.000
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-2.000
-4.000
Standardized Deviance Residual
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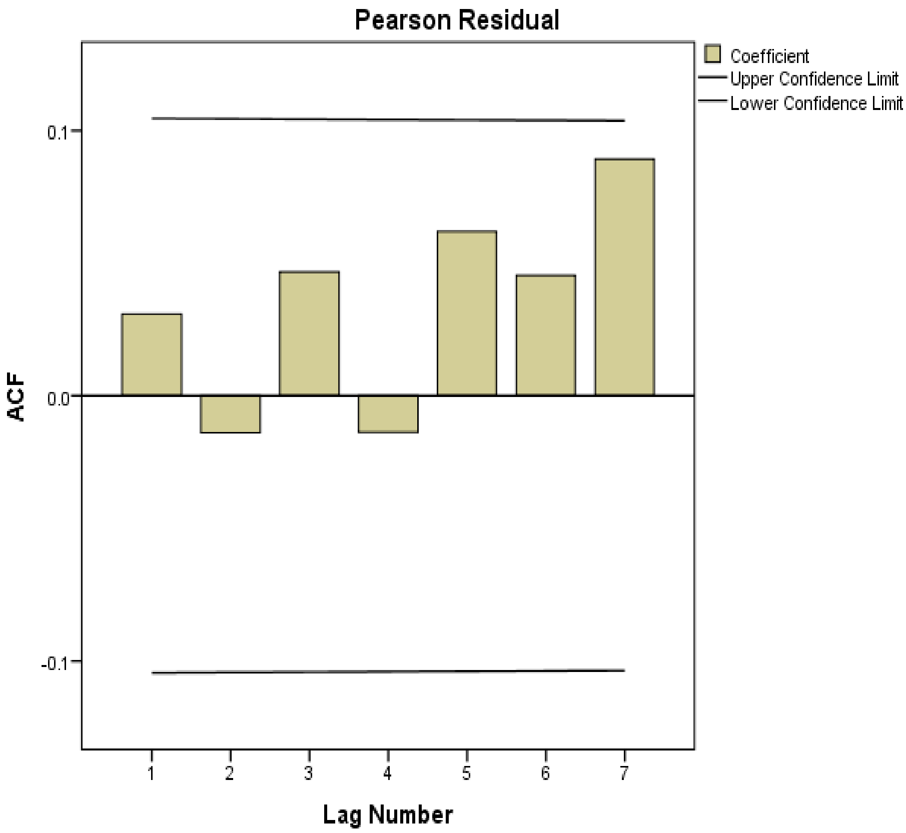
Predicted Value of Mean of Response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Coefficient
Upper Confidence Limit
Lower Confidence Limit
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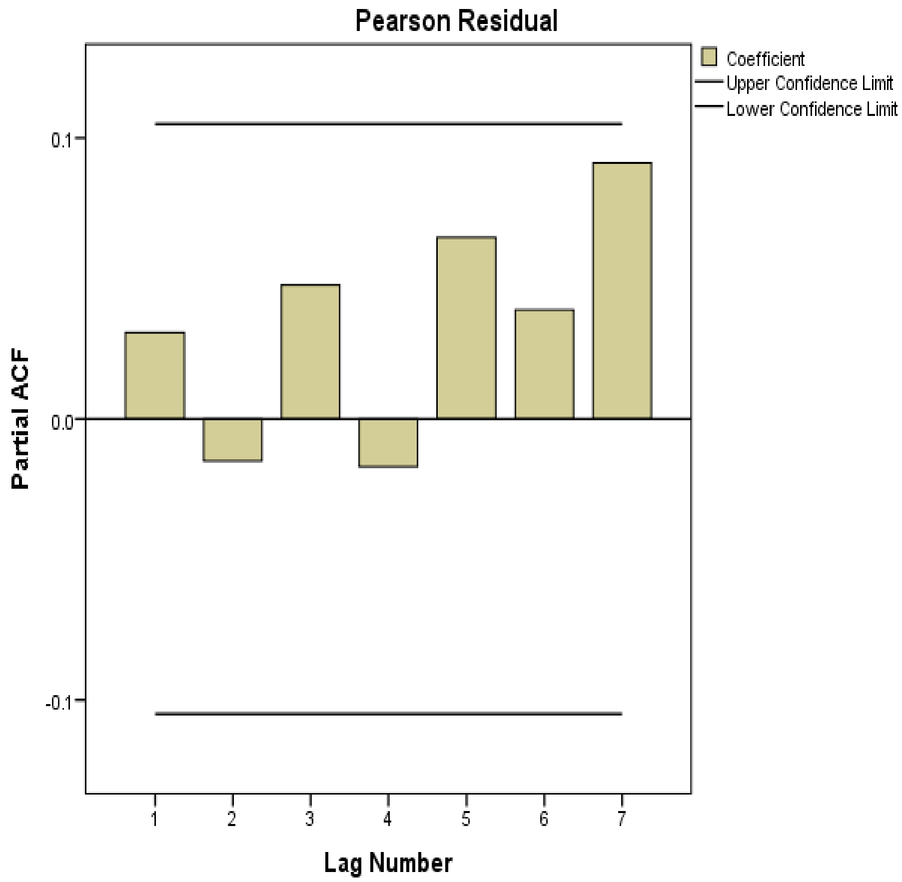
Lag Number


Pearson Residual
Coefficient
Upper Confidence Limit
Lower Confidence Limit
Partial ACF
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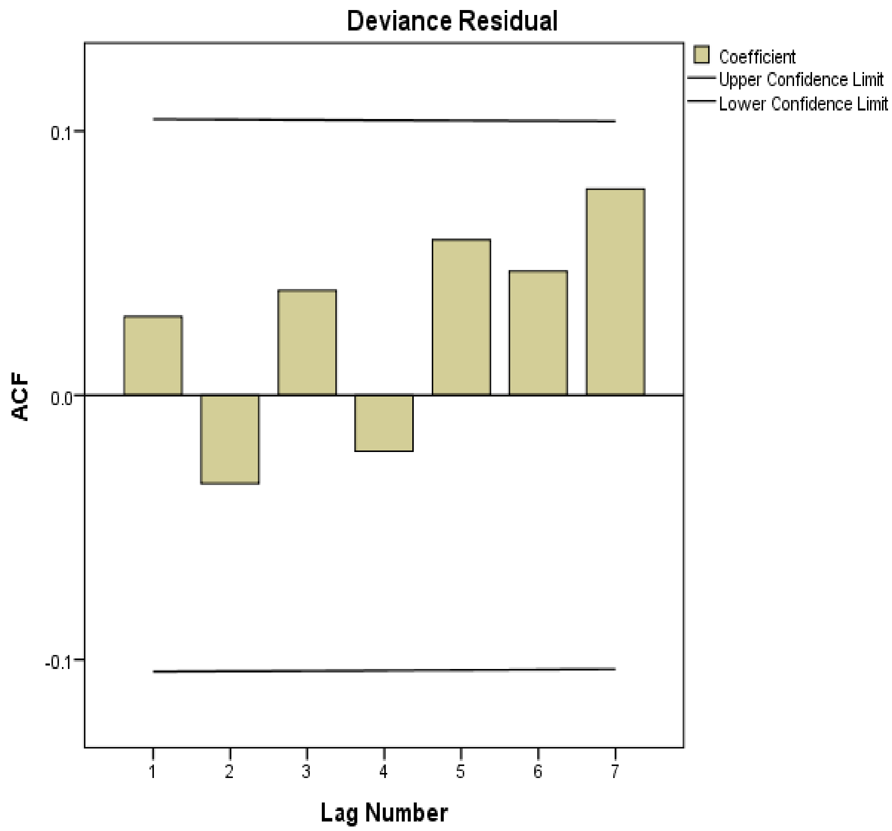
Lag Number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Coefficient
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Lower Confidence Limit
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Lag Number

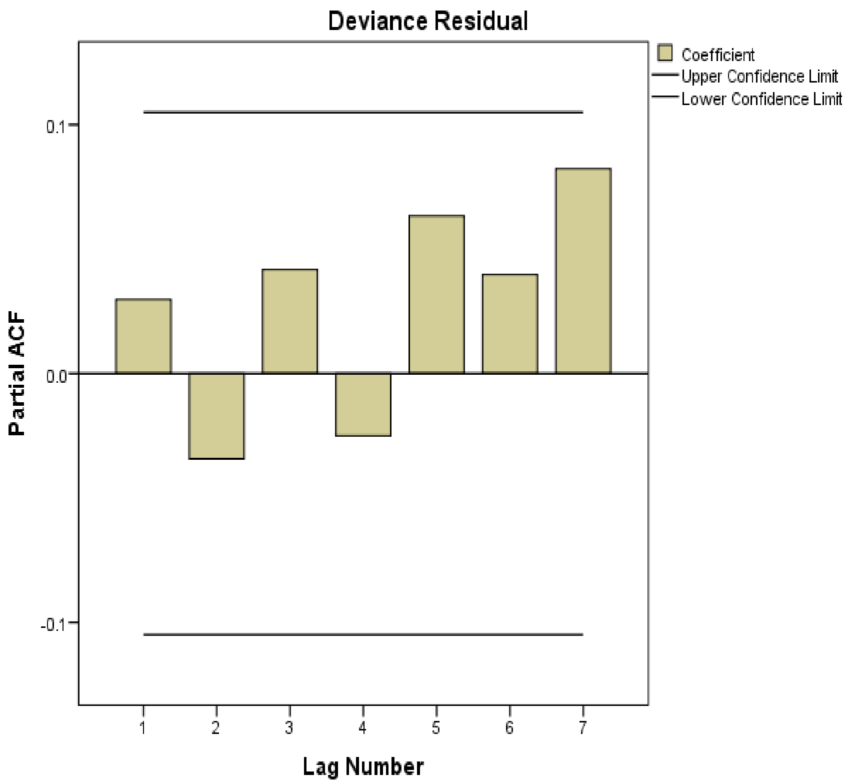


Figure 58 : Autoregressive aged respiratory effect model (address Kathmandu valley): Model adequacy test

3.3.6.5 Comparative assessment between aged respiratory effect GLMs

Table 111: Comparative assessment between aged respiratory effect GLMs

Particular	Respiratory		Respiratory (Autoregressive)		Respiratory KTM		Respiratory KTM (Autoregressive)	
	%	lag	%	lag	%	lag	%	lag
$PM_{2.5}$	1.21 (<0.01)	0	0.80 (<0.08)	0	2.94 (0.00)	0	1.82	0
CO	X	_	X	_	5.88 (0.06)	0	5.83 (0.07)	0
NO_2	9.6 (0.09)	2 day mean	7.5 (0.18)	2 day mean	X	_	X	_
Temperature	X	_	X	_	0.73 (0.07)	0	X	_
Relative Humidity	-2.91 (0.00)	2 day mean	-1.63 (0.00)	2 day mean	-3.09 (0.00)	0	-2.99 (0.00)	0
Rainfall	-0.6 (0.02)	2 day mean	-0.41 (0.01)	2 day mean	-0.64 (0.05)	2 day mean	X	_
Non-Saturday	51.4 (0.00)	-	52.5 (0.00)	-	46.7 (0.00)	-	45.8 (0.00)	
Autoregressive lag effects	-	-		1, 2 (+)	-	-		1, 2 (+)

Note: Temperature and relative humidity are either insignificant or associated with VIFs.

Interpretation / Assessment

Lag effects are found to be insignificant, with only same day effects of $PM_{2.5}$ statistically significant for respiratory hospitalizations of the subpopulation of people aged 50 and above. Comparing the percent change in respiratory hospital admissions per 10 µg/m^3 rise in $PM_{2.5}$, a higher increase is observed (around 3%) for Kathmandu residential inpatients compared to all inpatients (1.2%). Comparatively, autoregressive models show around 0.8-1.8% rise in respiratory hospitalizations per 10 µg/m^3 rise in $PM_{2.5}$. CO is only found to be statistically significant for Kathmandu residents, with positive same day lag effects. Around 5.8% increase in respiratory hospitalizations is observed per 1 mg increase in ambient CO for elderly individuals aged 50 and above. NO_2 is also found to be positively associated with respiratory hospitalizations (2 day mean effect) in this age group, with 9.6% and 7.5% increases in hospitalizations per 1 mg increase in ambient NO_2 for autocorrelation ignored and corrected models, respectively, and only when all addresses are considered. Temperature is found to be positively correlated with respiratory hospitalizations (same day effect) only for Kathmandu residents, with 0.7% increase in hospitalizations per 1^0 Celsius increase in temperature. Relative humidity is negatively correlated with respiratory hospitalizations in this age group, with 2 days mean effect for all-addresses inclusive models, and a same day effects amongst Kathmandu residents.

Autocorrelation ignored models show around 3% decrease in respiratory hospitalizations per 1% increase in relative humidity, whereas 1.6-3% decreases are seen in hospitalizations in autoregressive models. Rainfall is also negatively associated with respiratory hospitalizations in three of the four models developed (the autoregressive Kathmandu residential model is the exception), with around 0.4-0.6% decrease in respiratory hospitalizations per 1 mm increase in rainfall. The risk of hospitalization is greater on working days than holidays (i.e. Saturday) for all four developed COPD effect models, with around 45-52% increase in hospitalizations on non-Saturdays. Slight autocorrelations are observed for respiratory hospitalizations at 1 and 2 day lag models, which are corrected for in the autoregressive GLMs.

3.3.7 Mortality effect model

The GLM consisting of all-cause deaths (non-accidental) as the response variable is presented below.

Table 112: Mortality effect model

Parameter Estimates							
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.450	.2521	-.044	.944	3.183	1	.074
[Saturday=No]	.261	.0950	.075	.447	7.532	1	.006
[Saturday=Yes]	0[a]	.	.	.	.	.	.
$PM_{2.5}$_7 (Geo)	.0036	.0016	.000	.007	5.199	1	.023
CO_0	.1402	.0478	.047	.234	8.606	1	.003
NO_2_7 (Geo)	-.406	.2245	-.846	.035	3.262	1	.071
Temperature_0	.0140	.0078	-.001	.029	3.170	1	.075
a. Set to zero because this parameter is redundant.							

The GLM shows significant effects for one week geometric distributed lags of $PM_{2.5}$ (positive) and NO_2 (negative), and same day lag effects of CO (positive) and temperature (positive). The coefficients reveal the following relative risks and corresponding percent changes in all-cause mortality per unit (as indicated) increase in predictor values (or codes). Relative risks and percent increases are given below.

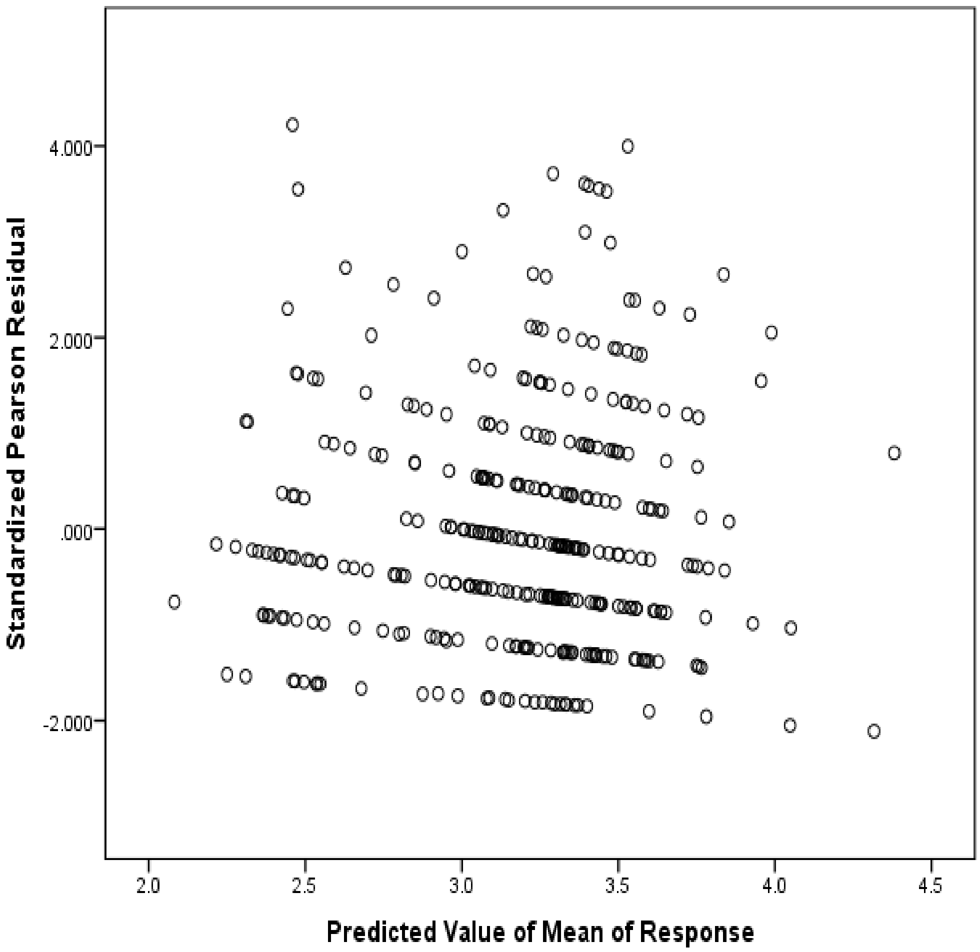
Table 113: Mortality effect model: Relative risks

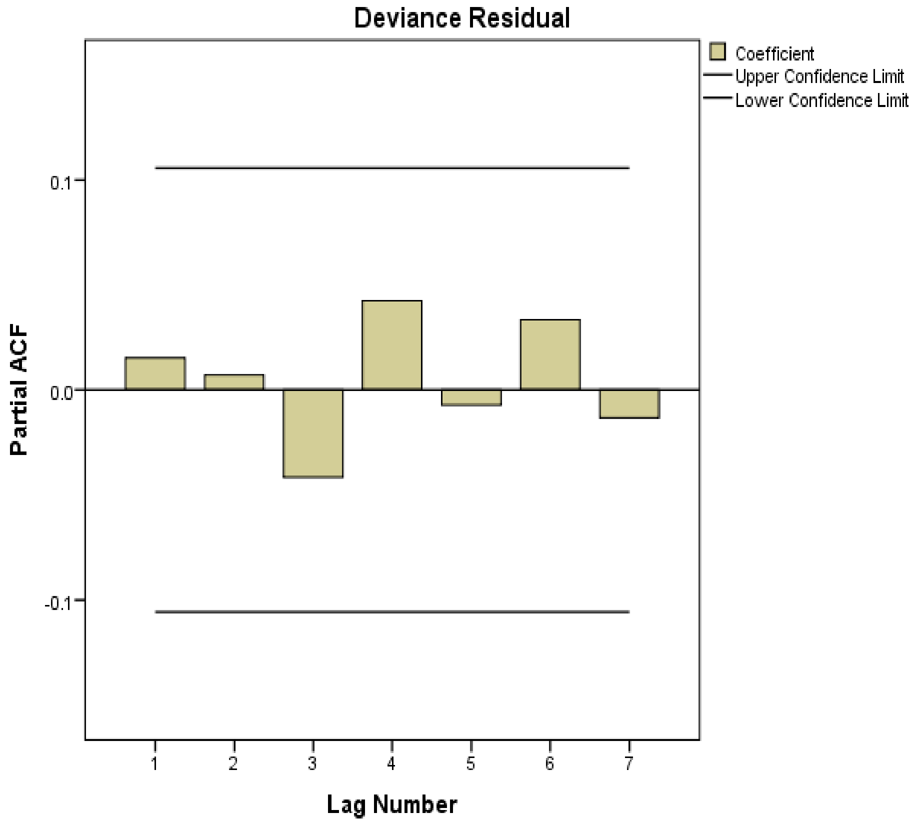
Predictor	Coefficient	Increase	Unit	RR	Percent Change
$PM_{2.5}$_7 (Geo)	0.0036	10	µg/m³	1.037	3.67
CO_0	0.1402	1	mg/m³	1.151	15.05
NO_2_7 (Geo)	-0.406	1	mg/m³	0.666	-33.37
Temperature_0	0.014	1	⁰C	1.014	1.41
Non-Saturdays*	0.261	1	-	1.298	29.82
*Categorical variable					

3.3.7.1 Model aadequacy test.

Table 114: Mortality effect model: Model adequacy test

Particular	Values	Assessment
Goodness of fit	Null Deviance=620.5 at 357 df; Residual Deviance:596.8 at 352 df Omnibus test: highly significant with log likelihood chi-square: (23.65 at 5 df; p <0.0001)	Good
Multicollinearity	VIFs<2.6	No multicollinearity
Heteroscadasticity	Scatterplots between residuals versus mean predicted values	Constant variance (ignoring three highest mean predicted observations)
Autocorrelation	Correlogram (up to lag 7)	No significant autocorrelations
Normality	KS test for deviance residual with p =0.2; normal q-q plot	Deviance residual normal (preferred)
Outlier	Scatterplots between residuals versus mean predicted values	Few detected but ignored

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Coefficient
Upper Confidence Limit
Lower Confidence Limit
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Partial ACF
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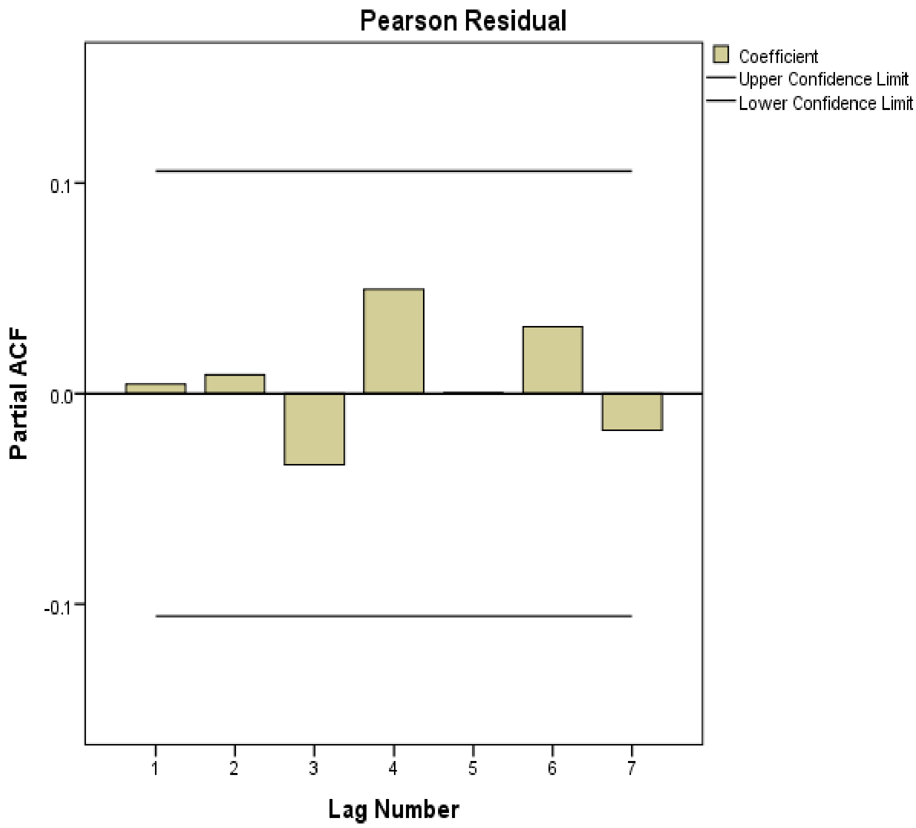
Lag Number


Pearson Residual
Coefficient
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Lag Number

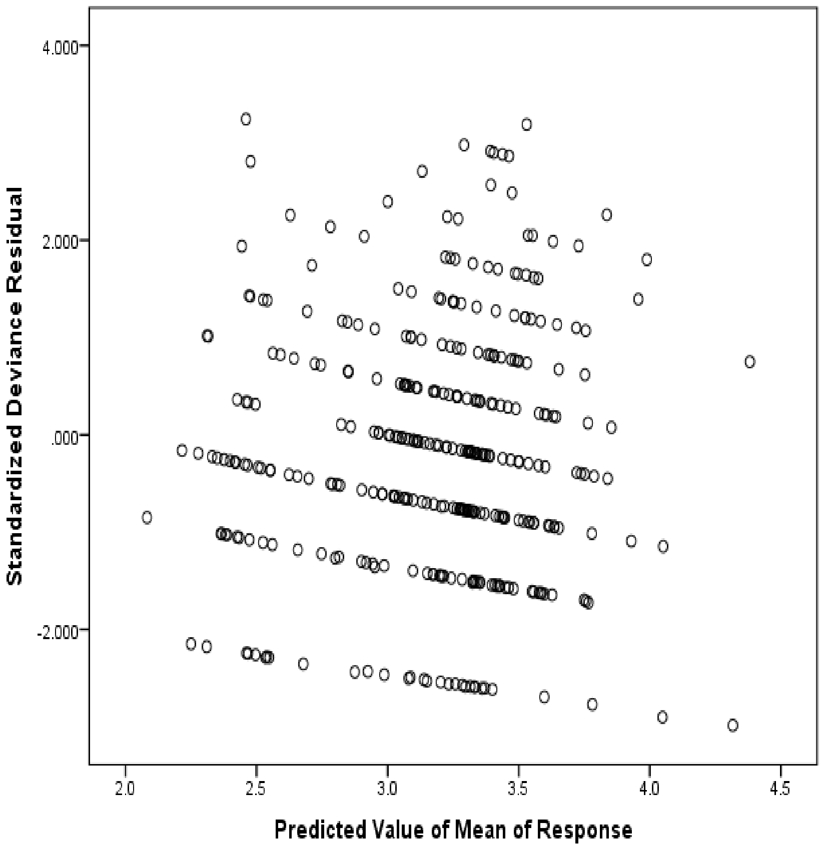

Figure 59: Mortality effect model: Model adequacy test

3.4 Assessment of Environmental Burden of Diseases (EBD) attributable to ambient air pollution

In this section EBD assessments attributable to ambient $PM_{2.5}$ and NO_2 are conducted, with CO excluded since ambient CO levels are within standard values for almost all daily averages. The assessment is carried out based upon methodology developed by WHO. The attributable fraction (AF) of a specified pollutant in the ambient air is calculated as follows:

$$AF = \frac{\left(\sum P_i RR_i\right) - 1}{\sum P_i RR_i}$$

RR_i = the relative risk at exposure category 'i' compared to a reference level. P_i is the proportion of days associated with different pollution concentration groups. Using AF, the expected EBD that can be attributed to a specific ambient air pollutant is given by:

$$EBD = AF \times \text{Total Burden}$$

Where total burden is the total disease burden from hospital records for a specified period of monitoring or the total burden obtained from DoHS annual reporting on the specified area around the same period of time (need not be the exact same period).

3.4.1 EBD assessment attributable to ambient $PM_{2.5}$

The frequency distribution of number of days with specified pollution level is shown below.

Table 115: EBD assessment attributable to ambient $PM_{2.5}$

$PM_{2.5}$ Level	Frequency (Days)	Percent	Cumulative Percent
0-20	102	27.9	27.9
20-40	56	15.3	43.3
40-60	72	19.7	63.0
60-80	75	20.5	83.6
80-100	32	8.8	92.3
100-120	17	4.7	97.0
120-140	8	2.2	99.2
140-160	1	0.3	99.5
160-180	1	0.3	99.7
180-200	1	0.3	100.0
Total	365	100.0	

The total burden of various respiratory diseases reported from hospitals morbidity register and as reported by DoHS for the year 2069-70 within Kathmandu Valley are as follows.

Table 116 : Total burden of respiratory diseases reported from hospitals morbidity register and DoHS

Disease	Number of cases
Pneumonia	12839
COPD	19847
Bronchitis	11139
Asthma	21671
ARI	78249
Ottitis Media	17043
Sinusitis	29157
Tonsillitis	14459
Lung cancer	228
TB	5046
Total	222517

The attributable fractions and burdens of diseases that can be attributed to ambient $PM_{2.5}$ in Kathmandu Valley are computed and shown in the following tables separately for hospital inpatients and morbidity reported in the annual report of the Department of Health Services

(DoHS) for the year 2069-70. The attributable fractions are computed based on estimates of autoregressive models with addresses in Kathmandu Valley and no threshold limit considered, since literature reviews indicate no such threshold limits exist for particulate pollution below which health effects can be neglected.

Hospital Inpatient Morbidity

Table 117: Hospital inpatient morbidity

Disease Burden	AF	Total Burden (Inpatients)	Attributable Burden
Respiratory	0.0483	11321	547
COPD	0.0625	4463	279
ARI	0.0953	5025	479
Pneumonia	0.1545	3292	509
Respiratory (Aged≥50)	0.0860	6207	534

Table shows the total hospital inpatient morbidity, where AF was found higher in pneumonia (0.1545).

Table 118: Total morbidity as reported in DoHS annual report

Disease	AF	Total Morbidity	Attributable Burden
Respiratory	0.0483	222517	10748
COPD	0.0625	19847	1240
ARI	0.0953	78249	7457
Pneumonia	0.1545	12839	1984

As per the DoHS annual report 2069-70, total morbidity which is caused by respiratory illness was found higher (222517) with AF of 0.0483 followed by ARI, COPD and pneumonia.

3.4.2 EBD assessment attributable to ambient NO_2

The attributable fractions and burdens of diseases that can be attributed to ambient NO_2 in Kathmandu Valley are shown in the following table separately for hospital inpatients and morbidity reported in the annual report of the DoHS for the year 2069-70. The attributable fractions are computed based on estimates of autoregressive models with addresses in Kathmandu Valley. The threshold limit of 80 $\mu g/m^3$ is accepted for EBD assessment.

Table 119: NO_2 level assessment

NO_2 Level	Frequency	Percent	Cumulative Percent
0-80	159	43.6	43.6
80-100	16	4.4	47.9
100-150	38	10.4	58.4
150-200	37	10.1	68.5
200-250	41	11.2	79.7
250-300	15	4.1	83.8
300-350	17	4.7	88.5
350-450	10	2.7	91.2
450-550	10	2.7	94.0
550-700	10	2.7	96.7
700-1000	8	2.2	98.9
1000-3500	4	1.1	100.0
Total	365	100.0	

Table 120: Burden of diseases attributed to ambient NO_2

Disease Burden	AF	DoHs Total Morbidity	Total Burden (Inpatients)	Attributable Burden (DoHs Morbidity)	Attributable Burden (Inpatients)
COPD	0.0534	19847	4463	1060	238
Respiratory (Aged≥50)	0.0162	-	6207	-	101

Burden of diseases attributed to ambient NO_2 which is higher in COPD (0.0534) in compared with Respiratory Aged≥50 (0.0162)

CHAPTER IV
DISCUSSION

4.1 Ambient air quality status in Kathmandu valley

Ambient air pollution has become a serious environmental concern and a public health risk in developing cites of developing countries, including Nepal. Major cities of Nepal are facing such problems. Due to its unique topographical situation, coupled with high emissions of pollutants, Kathmandu Valley is particularly vulnerable. However, latest data on ambient air quality in major cities of Nepal including of Kathmandu valley was not available to determine the degree of pollution. To get such data of Kathmandu valley, NHRC monitored ambient air quality ($PM_{2.5}$, CO and NO_2) of Kathmandu Valley continuously for a year. The monitoring period was from Falgun 2070 till Magh 2071, and showed that the valley's ambient air is polluted with harmful levels of $PM_{2.5}$ and NO_2, with daily 24-hour averages exceeding the daily Nepal's NAAQS for the majority of days (57.6% for $PM_{2.5}$ and 56.4% for NO_2) of monitoring. In the case of CO, only a single day exceeded the standard (using 8 hour averages). Many daily averages of $PM_{2.5}$ were 3-5 times higher than the standard of 40µg/m^3. Moreover, concentrations of NO_2 in the ambient air were found to be high, with several high spikes monitored above 1000 µg/m^3, which is around 12 times the 24-hour Nepal standard of 80µg/m^3. In a similar study conducted in China with the aim of reaching new air quality standards, air quality was monitored from August 2011 to February 2012, in 15 major cities out of 26. The concentration of $PM_{2.5}$ (57.5 µg/m^3) was higher than that recommended by WHO of 11.2 µg/m^3 (24 hour average value). Similarly, the concentrations of CO and NO_2 in those cities were in excess of the WHO recommended values (17). Conversely, NO_2 was higher at the Kathmandu station for only 5 of the 12 months, while for the remaining months Bhaktapur and Lalitpur exceeded recommended NO_2 levels. This signifies that NO_2 emissions from the months of Kartik-Poush, and during Chaitra may originate from sources such as generators, coal-powered factories etc. The study conducted in China, as well as one conducted in the capital of Romania, Bucharest, also suggested similar types of seasonal, daily and location-based variation in concentrations of $PM_{2.5}$, CO and NO_2 (17, 18).

Seasonal and monthly variations reveal that during winter and spring ambient air is highly polluted with $PM_{2.5}$, implying that colder and drier seasons are more risky compared to hot and wet months for valley inhabitants. It further demonstrates negative associations between fine particulate pollution levels and the meteorological variables temperature, humidity and rainfall. However, such correlations were not observed for CO. By comparison, CO levels were highest (though still within the standard) in both hot as well as cold months.. CO is a highly reactive species which typically undergoes immediate conversion to CO_2 (19). Other microenvironmental factors may play meaningful roles in disrupting associations in Kathmandu Valley between meteorological conditions and levels of ambient atmospheric pollution(20). In the case of NO_2 ambient air pollution, cold winter months were relatively more polluted than hot and wet months, similar to the situation for $PM_{2.5}$ pollution. Within 24-hour variation was also assessed to examine the possible variation of pollutant levels over different time periods such as morning, daytime, evening and night, since meteorological conditions (mainly temperature), and pollution emission activities vary across these time intervals. Interestingly, it was found that there exist definite patterns of cyclical variation in levels for all three pollutants monitored. Another situational analysis study of ambient air levels of $PM_{2.5}$, CO and NO_2 from March 2013 to March 2014 also showed changes from rainy to dry seasons for $PM_{2.5}$, CO, and NOx of 49-73 μg/m^3 (40%), 2.5-3.8 ppm (40%), and 144-252 ppb (53%), respectively (21).

$PM_{2.5}$ hourly levels are at their lowest (below 40 μg/m^3) during the post-midnight until pre-dawn period (0-5 AM). They gradually increase throughout the morning and attain their highest level (87 μg/m^3) during 8-9 AM. Levels then decrease to their lowest value (31 μg/m^3) during the afternoon (2-3 PM). Thereafter, levels increase again, reaching a peak (59 μg/m^3) at 8-9 PM before gradually decreasing late at night. Hourly NO_2 averages show cyclical variation similar to $PM_{2.5}$ hourly variation. The averages are consistently much higher than the 24-hour standard of 80 μg/m^3, which reveals that Kathmandu Valley is highly polluted with ambient NO_2 pollution. Relatively, levels are on the lower side in the period after midnight until pre-dawn (160-170 μg/m^3) and start rising in the early morning (5-6 AM). Levels rise to around 270 μg/m^3 by 9-10 AM and decrease gradually during the daytime to reach around 140 μg/m^3 by 4-6 PM. The levels then again rise, to around 180 μg/m^3, at 6-9 PM, then decrease through until midnight (150 μg/m^3). The pollution increases during the morning may be partly due to increasing activities of the human population, and increase in traffic density in particular, and it poses a health threat to morning walkers. In Mexico City, $PM_{2.5}$ reaches its maximum concentration between 7 and 11 AM depending on the season: warm-dry, cold-dry, or rainy. It is reported that this large shift in the peak of the daily cycle is the result of both the atmospheric dynamics, i.e. boundary layer growth, and the chemical process behind the formation and growth of the particles that make up $PM_{2.5}$ and NO_2 (21). In Nepal, hourly averages of CO are very low from midnight until pre-dawn (less than 200 μg/m^3) and start to increase from early morning (5-6 AM), reaching around 635 μg/m^3 by 10-11 AM. The level remains relatively high throughout daytime until 2-3 PM (500-670 μg/m^3), then dips to around 400 μg/m^3 during 4-5 PM. The level then again increases to a maximum of around 725 μg/m^3 at 7-8 PM, and decreases thereafter through midnight (189 μg/m^3) till the pre-dawn period (118 μg/m^3). However, despite this variation, values remain well below the 8 hour NAAQS of 10000 μg/m^3 at all times. Health impact of CO is therefore expected to be negligible, though it's of note that the pattern of hourly variation of CO is similar to that of $PM_{2.5}$ and NO_2, which are both above the safe limit.

Schedule power outage is becoming a major challenge for Nepal, and is giving rise to direct and indirect impacts in the realm of socioeconomics, cultural, and health of the population. At present, the nation is facing problems of power outage for more than 12 hours daily except in the rainy season, when larger amounts of hydro electricity are available. $PM_{2.5}$ pollutants in ambient air was found to be 1.33 times higher during scheduled power outage times at all three stations of Kathmandu Valley. The higher levels of $PM_{2.5}$ during power outage times may be due to the use of generators or other types of fuel which create particulate pollution. This is the first time such data have been generated in Nepal, and therefore provides a unique insight into the current status of ambient air quality.

4.2 Respiratory health effects

Various epidemiological studies show statistical association between levels of individual or combined air pollutants and outcomes, such as rates of asthma, lung cancer, heart problems, emergency visits for asthma; or hospital admissions, mortality and respiratory health outcomes (22, 23). Children and aged adults are most vulnerable to ambient air pollution in major cities around the world, and adverse health effects have been seen more clearly in developing countries than developed ones (5). There are long-term adverse effects of air pollution, such as changes on lung function of children and reduction in lung function capacity at the end of adolescence (24).

In the present study, it is reported that among all respiratory diseases, COPD (4463), pneumonia (3292) and ARI excluding pneumonia (1733) were the leading causes of respiratory inpatient hospitalizations in Kathmandu Valley hospitals. Comparative assessment between different age groups shows that children (0-9) and aged persons (50 and above) are the most vulnerable groups with regards to respiratory ailments, with 25.5% of patients being children and around 55% being aged persons. Only around 20% of inpatients belonged to the young/middle aged group (10-49). Gender-wise, male inpatients were slightly more common (51.3 %) than female inpatients. Mean age is highest for COPD inpatients (65.6) and lowest among ARI and patients with other respiratory symptoms (5-7.5). Mean age is around 40 years for several diseases such as pneumonia, asthma, bronchitis, and pleural effusion. These findings are consistent with those of other studies documenting health effects of ambient air pollution around the world. Furthermore, a steady seasonal trend of decreasing total number of cases of respiratory hospitalizations was seen from spring to winter, which is similar to findings from previously conducted studies. From spring to winter, there is a rise of ambient air pollution concentration and concurrent rise in cases of hospitalization due to respiratory ailments, whereas in the rainy season hospitalization rates decrease in line with ambient air pollutant levels (16).

$PM_{2.5}$ is positively correlated with most of the hospitalizations considered, whereas CO and NO_2 monthly means are negatively associated with respiratory hospitalizations, barring a few exceptions for NO_2. Temperature is found to be positively associated with respiratory disease incidence except for COPD, whereas rainfall and relative humidity are found to be negatively associated with respiratory hospitalizations. However, it must be noted that most of the correlations are not statistically significant, suggesting observed correlations may not carry real public health ramifications. Disease burden is also associated with certain weather parameters such as temparature, rainfall and humudity, as well as with sanitation conditions. However, sometimes the relationship between human health risk and weather variables is more complex phenomena with respect to medical and social perspectives (25). The following health effects were observed per 10 µg/m^3 rise in $PM_{2.5}$: 1-1.4% increase in respiratory hospitalizations (same day lag effects), 1-2% increase in COPD hospitalizations (same day lag effects), 2-2.8% increase in ARI hospitalizations (7 day geometric and 2 day mean effects), 3.2-4.7% increase in pneumonia hospitalizations (7 day arithmetic and geometric lag effects) and 0.8-3% increase in all-cause respiratory hospitalizations for aged individuals (50 and above). NO_2 showed significant negative correlations with ARI, pneumonia and respiratory hospitalizations for children and adolescents, though positive correlations with COPD hospitalizations of people aged 50 and above. A previous study has reported that 10 µg/m^3 increase of $PM_{2.5}$ is associated with 3% increase in pneumonia visits to hospital, and increases of 1 standard deviation in NO_2 and CO were associated with 2–3% increases in COPD visits (26).

It was determined that every 1^0 Celsius rise in temperature correlated with an increase of 0.65-1% in respiratory hospitalizations (same day lag effect), 1.4-2.4% in ARI hospitalizations (7 day mean and 7 day geometric lag effects), 1.4-2.2% in pneumonia hospitalizations (7 day arithmetic and 7 day geometric lag effects), and 0.7% in respiratory hospitalizations (same day effect) amongst people aged 50 and above (Kathmandu residents only). Conversely, relative humidity was associated with 0.6-1.6% decrease in respiratory hospitalizations (same day effect), 1.9–3.6% decrease in COPD hospitalizations, and 1.6–3% decrease in respiratory hospitalizations for people aged 50 and above. Relative humidity also showed negative non-significant associations with pneumonia, ARI, asthma and respiratory disease hospitalizations.

As regards all-cause mortality, the developed GLM showed statistically significant effects for one week geometric distributed lag of $PM_{2.5}$ (positive) and NO_2 (negative), and same day lag effects of CO (positive) and temperature (positive). The magnitude of these effects were: 3.7% rise in mortality per 10 µg/m^3 rise in $PM_{2.5}$ (7 day geometric lag effect); 0.15-0.7% rise in mortality per 10 µg/m^3 rise in CO (same day effect), and 1.4% rise in mortality per 1^0 Celsius rise in temperature (same day effect). The World Health Organization has estimated that 3.7 million premature deaths were caused worldwide in 2012 due to ambient air pollution, and 88% of those premature deaths occurred in low- and middle-income countries, the greatest number being in the Western Pacific and South-East Asia(4). However, disease burden has not been categorized into particular disease fractions attributable to ambient air quality. In this study, analysis of environmental burden of disease that can be attributed to ambient air pollution reveals that attributable fractions range between 0.05 and 0.15, the lowest being for all respiratory diseases and the highest being for pneumonia, with 547 and 509 hospital cases attributable to ambient $PM_{2.5}$ for the study period (2070-71) respectively. Fraction attributable to ambient NO_2 was lower, with 238 (AF=0.05) and 101 (AF=0.02) cases for COPD and respiratory (aged 50 and above) hospitalizations, respectively. Considering an older study of PM_{10} ambient air pollution, there were 212 attributable cases of premature mortality per year, with between 127 and 338 attributable cases of various respiratory diseases in 2004. It is difficult to compare that finding to current data as different ambient pollutants were assessed in each study (1).

CHAPTER V
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Conclusions are presented separately in sub-sections as follows.

5.1.1 Status of ambient air pollution in Kathmandu valley

The overall scenario for Kathmandu Valley based upon analysis of data on ambient $PM_{2.5}$, CO and NO_2 is that the ambient air is polluted with harmful concentrations of $PM_{2.5}$ and NO_2. 24-hour averages exceeding the daily Nepal's NAAQS were detected for the majority of days monitored (57.6% for $PM_{2.5}$ and 56.4% for NO_2) from Falgun 2070 until Magh 2071. In the case of CO, only a single day exceeded the standard (using an 8 hour average). Many daily averages of $PM_{2.5}$ were 3-5 times higher than the standard of 40µg/m^3. The situation seems even more problematic for NO_2 ambient air pollution, with several very high spikes monitored above 1000 µg/m^3,around 12 times higher than the 24-hour Nepal standard of 80 µg/m^3 NO_2.

Station-wise results reveal that Kathmandu is the most highly polluted with $PM_{2.5}$ and CO for the majority of monitored months. This may be attributable to higher traffic density and other activities in Kathmandu relative to the other station areas in the valley. However, NO_2 was higher at Kathmandu station for only 5 months. In the remaining months, Bhaktapur and Lalitpur exceeded Kathmandu for 4 months each (in one month both stations had the same high value).

5.1.1.1 Seasonal variation

$PM_{2.5}$ is the highest in spring and winter (above 70 µg/m^3) and the lowest in monsoon and autumn months (below 25 µg/m^3). CO is the lowest in autumn (298 µg/m^3) and relatively high in winter (517 µg/m^3) as well as in summer (503 µg/m^3), showing seasonal means high in dry as well as in wet conditions, which suggests that temperature and rainfall are not correlated with means of CO levels. NO_2 is highest in spring (267 µg/m^3) and Winter (315 µg/m^3), and relatively low in monsoon (97 µg/m^3) and autumn months (lowest: 47 µg/m^3)). Similar to $PM_{2.5}$ seasonal variation, NO_2 shows relatively low levels during hot seasons and high levels in dry seasons, so it seems that meteorological conditions do have significant effects on NO_2 levels.

5.1.1.2 Monthly variation

A trend of declining monthly averages of $PM_{2.5}$ was seen from the month of Falgun, 2070 (79.5 µg/m^3) to Shrawan, 2071 (9.9 µg/m^3), and an increasing trend from Shrawan 2071 to Manshir

2071 (82.2 μg/m^3); a slight decrease in Aswin 2071 (78.4 μg/m^3) and Poush 2071 (85.5 μg/m^3) was also seen. This demonstrates that warmer months are relatively less polluted with $PM_{2.5}$ in the ambient air of Kathmandu Valley compared to colder months. The correlation matrix shows statistically significant negative correlations (-0.4 to -0.9) between $PM_{2.5}$ levels and weather parameters. There was a cyclic variation in monthly average of CO as it rose from Falgun 2070 (384.9 μg/m^3) to Baishak 2071 (576.6 μg/m^3); decreased in Jestha 2071 (208.8 μg/m^3) and again increased until Shrawan 2071 (742.6 μg/m^3). It then decreased until Aswin (151.4 μg/m^3), increased until Poush 2071 (626.5 μg/m^3) and then decreased in Magh 2071 (424.9 μg/m^3). The correlation matrix shows that no statistically significant association exists between CO and any meteorological parameters. Monthly NO_2 levels were low from Shrawan (32 μg/m^3) to Kartik (70.9 μg/m^3), very high from Magh to Falgun and Baishak (around 350-530 μg/m^3), and high for the remaining months (above 90 μg/m^3). On average, winter and dry months (the highest in Magh) had higher NO_2 levels compared to warm and wet months. The negative link between NO_2 levels and meteorological parameters is supported by statistically significant correlations as shown in the correlation matrix (-0.39 to -0.63)

5.1.1.3 Within 24 hours variation

Within 24-hour variation was also assessed to examine the possible variation of pollutant levels at different time periods, such as morning, day, evening and night, as meteorological conditions, particularly temperature, and more importantly pollution emission activities vary over these time intervals. Interestingly, it was found that there exists definite patterns of cyclical variation in pollution levels for all the three pollutants monitored.

$PM_{2.5}$ pattern

Observing the $PM_{2.5}$ variation, it is found that the level was the lowest (below 40 μg/m^3) during post-midnight and before dawn (0-5 AM). It gradually increases throughout the morning and reaches a peak (87 μg/m^3) from 8-9 AM. Thereafter, it gradually decreases to its lowest value (31 μg/m^3) during the afternoon (2-3 PM). The level then increases again and attains a second peak (59 μg/m^3) at 8-9 PM before gradually decreasing late at night. It seems highly likely that during morning time the gradual level increase may be partly due to increasing activities of the human population, particularly increasing traffic density. This poses health threats to morning walkers.

CO pattern

Hourly averages of CO are very low after midnight and before dawn (less than 200 μg/m^3) and start to increase during the early morning (5-6 AM), reaching around 635 μg/m^3 by 10-11 AM. The level remains relatively high throughout the day until 2-3 PM (500-670 μg/m^3) and decreases slightly to around 400 μg/m^3 by 4-5 PM. The level again increases to around 725 μg/m^3 by 7-8 PM, and decreases thereafter through midnight (189 μg/m^3) until the before-dawn period (118 μg/m^3). Hourly recordings show the lowest values during midnight through till before dawn, and the highest during the daytime , especially from 12-3 PM and at 7-8 PM. Nonetheless, values are well below the 8 hour NAAQS of 10000 μg/m^3.

NO_2 pattern

Hourly NO_2 averages show cyclical variation similar to $PM_{2.5}$. The averages are consistently much higher than the 24-hour standard of 80 μg/m^3, which reveals that Kathmandu Valley is highly polluted with ambient NO_2. Relatively, the level is on the lower side after midnight and in the before-dawn period (160-170 μg/m^3), and starts rising in the early morning (5-6 AM). The level rises to around 270 μg/m^3 by 9-10 AM and decreases gradually throughout the day to around 140 μg/m^3 by 4-6 PM. The level then again rises to around 180 μg/m^3 by 6-9 PM before decreasing though till midnight (150 μg/m^3).

$PM_{2.5}$ levels were also assessed to examine possible differences in levels during load shedding time compared to normal time when electricity was available. It is found that $PM_{2.5}$ pollution in ambient air was 1.33 times higher during load shedding. The higher levels of $PM_{2.5}$ during scheduled power outage time may be due to use of generators or other sources of fuel which pollute ambient air with particulate pollution. All three stations showed higher ambient $PM_{2.5}$ levels during power outage. The ratio of $PM_{2.5}$ for power outage time compared to normal time is the highest (1.36) in Lalitpur and the lowest in Kathmandu (1.28).

5.1.2 Health effects and its statistical modeling

5.1.2.1 General respiratory inpatient health status/effects

Tribhuvan University Teaching Hospital (TUTH), Patan hospital and OM hospital showed the highest numbers of respiratory inpatients (more than 1000) during the year (2070-71), while six other hospitals had inpatients numbers between 500 and 1000. Four hospitals (Siddhi memorial hospital, Bhaktapur hospital, Ishan hospital and Civil hospital) received less than 500 inpatients each, giving a total of 11321 inpatients for the monitored year. Among the considered diseases, COPD (4463), pneumonia (3292) and ARI excluding pneumonia (1733) were the leading respiratory diseases in Kathmandu Valley hospitals.

Comparative assessment between different age groups shows that children (0-9) and aged persons (50 and above) are the most vulnerable groups as regards respiratory ailments, with 25.5% of patients being children and around 55% being aged persons. Only around 20% of inpatients belonged to the young/middle aged group (10-49). Gender-wise, male inpatients were slightly more frequent (51.3 %) than female inpatients. Mean age was the highest for COPD inpatients (65.6) and the lowest among patients with ARI or respiratory symptoms (5-7.5). Mean age was around 40 years for several diseases such as pneumonia, asthma, bronchitis, and pleural effusion. Of all inpatients, 65.7% were resident of Kathmandu Valley, and 34.3% were from outside Kathmandu Valley. Among ARI inpatients, 29.1% also had pneumonia, which is a common co-morbidity among ARI inpatients. There was a steadily decreasing seasonal trend seen from spring to winter for both the total number of cases of respiratory hospitalization and for patients with addresses in Kathmandu Valley. This is perhaps a typical result specific to the monitored year, as winter months in the past have generally seen higher numbers of respiratory inpatients. Correlations between monthly numbers of inpatients, averages of pollutant levels and weather parameters showed that $PM_{2.5}$ was positively correlated with most of the diseases considered, whereas in contrast, CO and NO_2 monthly means were negatively associated with respiratory hospitalizations, barring a few exceptions for NO_2. Temperature was found to be positively associated with respiratory diseases except for COPD, whereas rainfall and relative humidity were found to be negatively associated with respiratory hospitalizations. However, it is notable that most of the correlations are not statistically significant, suggesting the observed correlations may not be meaningful.

5.1.2.2 Statistical models of health effects

The health effects which can be attributed to ambient air pollution in Kathmandu Valley were assessed by respiratory morbidity, reported as hospitalizations, and mortality, assessed by all-cause non-accidental deaths in leading hospitals within the valley. Generalized linear models were used to associate health effects with multiple ambient air pollution parameters ($PM_{2.5}$, CO and NO_2), while accounting for various confounding variables such as temperature, humidity, rainfall, season, and day of the week. Responses considered were hospital inpatients counts of all respiratory disease, COPD, ARI, pneumonia, age-specific and address-specific respiratory disease. Since past studies indicated that distributed lag effects of ambient air pollution and confounders like several past day mean, geometric lag effect, etc. has statistically significant effects as explanatory variables, these were explored and used wherever appropriate. The main different schemes or functional forms of lag effects explored were same day effect, mean effect of same and past days effect (2 day, 4 day, week, two weeks, etc), geometrical lag effect (4 day, week, two week, etc.), and arithmetical lag effect (4 day, week, two week, etc.). Final selected statistical models were presented after rigorous exploration of different combinations of predictors including different forms of with and without lag structures of the explanatory variables. Moreover, models were screened with different main model adequacy measures, namely goodness of fit, normality, heteroscadasticity, multicollinearity, autocorrelation and outliers. Corrected models were also generated with additional lagged dependent variables to address the autocorrelation problem; autocorrelation is likely since models are based upon time series data. Upon examination, slight autocorrelation does exists with all the developed models for morbidity hospitalizations. As such, two models were generated for each dependent variable examined: one without lagged term(s) of hospitalizations and another with lagged terms corrected for autocorrelation for morbidity hospitalizations. Both are considered since the autocorrelations detected are only slightly significant in all cases, and as such may arguably be ignored. Altogether 25 models were developed.

5.1.2.2.1 Respiratory hospitalizations

Increase in respiratory hospitalizations were detected, being slightly higher (1.41%) for Kathmandu resident inpatients compared to all inpatients (1.014%). Autoregressive models (1, 2, 5 and 7 day lags) also show around 1% rise in respiratory hospitalizations per 10 µg/m^3 rise in $PM_{2.5}$. CO and NO^2 were found to be statistically insignificant. Effect of temperature was lower in autocorrelation corrected models (around 0.65% increase in respiratory morbidity per 10° Celsius increase in temperature) compared to around 1% in uncorrected models. A similar increase (1%) was seen for both all-resident models and Kathmandu residents models. Rainfall was associated with around a 0.33% decrease in respiratory hospitalizations per 1mm increase in rainfall. Around a 0.6-1.6% decrease in respiratory hospitalizations was observed per 1% increase in relative humidity. Around 40-50% increase in hospitalizations occurred on non-Saturdays. Same day lag effects were detected for respiratory hospitalizations, indicating the absence of distributed lag effects.

5.1.2.2.2 COPD hospitalizations

Around 1-2% increase in COPD hospitalizations was seen (same day lag effect) for each 10 µg/m^3 rise in $PM_{2.5}$, with relatively higher a change (2%) for Kathmandu resident inpatients compared to all-addresses inpatients (1.4%). Autoregressive models (1 and 2 day lags) show around 1-1.3% rise in COPD hospitalizations per 10 µg/m^3 rise in $PM_{2.5}$, lower than the autocorrelation uncorrected models. Two and 7 day positive lag effects were detected for NO_2, with high variability in effects between models. Comparatively, NO_2 had a greater impact (7 day mean effect) for inpatients with Kathmandu addresses (26-31%) compared to 9-12% for all addresses inclusive. CO and temperature were found to be statistically insignificant for all the four developed COPD effect models. Relative humidity (same day negative effect) was associated with 3.2-3.6% decrease in COPD admissions per 1% rise in relative humidity for both all-address models and Kathmandu address models. Rainfall was also negatively associated (same day effect) with around 0.7% decrease in COPD hospitalizations per 1% increase in relative humidity for all-address inclusive models, and with around 0.5% decrease for Kathmandu address models.

Around 48-55% increase in COPD hospitalizations was observed for non-Saturdays.

5.1.2.2.3 ARI hospitalizations

Overall 2-2.8% increase in ARI hospitalizations was detected with 7 days geometric lag and 2 days mean effect per 10 µg/m^3 rise in $PM_{2.5}$, with a smaller increase (2%) seen for the autocorrelation-corrected Kathmandu resident inpatients model (1, 3, 4, 5 and 7 day lags) compared to other ARI response models (around 2.7-2.8%). CO and NO_2 were found to be significantly and negatively associated with all-address inclusive models for ARI hospitalizations, whereas NO_2 was associated with ARI morbidity with 7 days lag for three of the four developed ARI effect models. Relative humidity was found to be statistically insignificant, while temperature was positively associated with a weeklong (7 days mean and 7 day geometric lag) effects on ARI hospitalizations. The percent change in hospitalizations per 10° Celsius increase in average temperature was found to vary between 1.4-2.4%. Rainfall was also associated with around 1-1.3% decrease in ARI hospitalizations per 1mm increase in average rainfall for ARI models not corrected for autocorrelation. Rainfall was insignificant for autoregressive models. Around 37-42% increase in ARI hospitalizations was observed for non-Saturdays.

5.1.2.2.4 Pneumonia hospitalizations

The effect of $PM_{2.5}$ was the highest (3.2-4.7%) for pneumonia hospitalizations among all respiratory hospitalizations, with 7 days lag effect (arithmetic and geometric decays), arithmetic decay for the all-addresses inclusive model, and geometric decay for the Kathmandu Valley address model. Comparing the change in pneumonia hospital admissions per 10 $\mu g/m^3$ rise in $PM_{2.5}$, it is observed that the change was higher (4.71%) for the all-address inclusive model, whereas 3.3-3.6% increase was seen for other three models.CO and NO_2 were found to be statistically significant and negatively associated in some of the models with 7 days lags (arithmetic and geometric). CO is insignificant for autoregressive pneumonia models but significantly negatively associated with pneumonia hospitalizations in autocorrelation ignored models. NO_2 was negatively associated only with the all-addresses inclusive model and was insignificant for the other three models. Temperature was found to be statistically significant and positively associated with 7 days arithmetic decay for the all-addresses inclusive model and 7 days geometric decay for the Kathmandu Valley address model, with 1.4-2.2% increase in pneumonia hospitalizations per 10° Celsius rise in temperature. Relative humidity was statistically insignificant. Rainfall was negatively associated with pneumonia hospitalizations in the autocorrelation-ignored models with 7 days lag effect, but insignificant in autoregressive models. The decrease in pneumonia hospitalizations ranges from 1.6-2.2% per 1 mm increase in rainfall. Around 43-48% increase in pneumonia hospitalizations was seen for non-Saturdays.

5.1.2.2.5 Children & adolescents (ages ≤19) respiratory hospitalizations

$PM_{2.5}$ and CO were found to be statistically insignificant for respiratory hospitalizations when the sub-population comprising children and adolescents aged 19 and less was considered, a contrasting result to the other models developed. NO_2 was negatively associated with respiratory hospitalizations with 7 days lag effect. Rather than temperature, seasonal indicator variables were found to be more significant for respiratory hospitalizations in this sub-population, also a different result than that obtained for the whole population. Further, when temperature and relative humidity are included the models either suffer from the problem of multicollinearity or the variables are statistically insignificant. Rainfall was found to be negatively associated with respiratory hospitalizations when only Kathmandu residents were considered, with around 1% decrease in respiratory hospitalizations per 1% increase in relative humidity. Around 28-44% increase in respiratory hospitalizations was observed for non-Saturdays.

5.1.2.2.6 Aged (age ≥50) respiratory hospitalizations

Only same day effects of $PM_{2.5}$ were found to be statistically significant when considering respiratory hospitalizations for the aged 50 and above sub-population. The percent change in hospitalizations was higher (around 3%) for Kathmandu resident inpatients compared to all-addresses inclusive inpatients (1.2%). Moreover, autoregressive models (1 and 2 day lags) showed only around a 0.8-1.8% rise in respiratory hospitalizations per 10 μg/m³ rise in $PM_{2.5}$. CO was found to be statistically significant for Kathmandu residents only, with a positive same day lag effect. Around 5.8% increase in respiratory hospitalizations was detected per 1 μg/m³ increase in ambient CO for people aged 50 and above. NO_2 was also positively associated with respiratory hospitalizations (2 days mean effect) in this age group with 9.6% and 7.5% increase in hospitalizations per 1 μg/m³ increase in ambient NO_2 for autocorrelation ignored and corrected models respectively, and only when all-addresses inclusive are considered. Temperature was found to be positively associated (same day effect) only for Kathmandu residents, with 0.7% increase in respiratory hospitalizations per 10° Celsius increase in temperature. Relative humidity was found to be negatively associated with respiratory hospitalizations in this age group, with 2 days mean effect for all-addresses inclusive models, and same day effect for Kathmandu residents. Autocorrelation ignored models showed around 3% decrease in respiratory hospitalizations per 1% increase in relative humidity, whereas 1.6-3% decrease in hospitalizations was seen in autoregressive models. Rainfall is also negatively associated with ≥50 year respiratory hospitalizations in all of the models developed except the autoregressive Kathmandu resident model, with around 0.4-0.6% decrease in respiratory hospitalizations per 1 mm increase in rainfall. Around 45-52% increase in respiratory hospitalizations was observed for non-Saturdays.

5.1.2.2.7 All cause mortality

The developed GLM showed statistically significant one week geometric distributed lag effects of PM2.5 (positive) and NO2 (negative), and same day lag effects of CO (positive) and temperature (positive). Autocorrelation is not found to be significant in the developed models, so autoregressive models were not developed. PM2.5 was associated with 3.7% rise in mortality per 10 μg/m3 rise in PM2.5 (7 day geometric lag effect), CO was associated with 0.15% rise in mortality per 10 μg/m3 rise in CO (same day effect), temperature was associated with 1.4% rise in mortality per 10° Celsius rise in temperature (same day effect), and non-Saturdays were associated with 30% rise in mortality compared to Saturdays.

5.1.2.2.8 Model adequacy tests

Various standard model adequacy measures were adopted for acceptance of the developed models. These are goodness of fit, normality, heteroscadasticity, multicollinearity, autocorrelation and outliers. Goodness of fit was judged by Omnibus test and found to be good for all the models developed. Normality as assessed by K-S tests showed insignificant p-values, suggesting normality for deviance residuals. The constructed q-q plots showed slight deviations from normality for Pearson residual, which was ignored. Multicollinearity assessed by VIF showed values less than 5, which is suggestive of the absence of multicollinearity. Heteroscadasticity as assessed by residual plots of standardized Pearson and deviance residuals versus predicted values demonstrated fairy constant variances with one or two outliers (ignored). Slight autocorrelation problems do exist in the developed models, which can arguably be ignored. However, in the interest of constructing more refined models, autoregressive models were developed with significantly reduced autocorrelations, making them statistically insignificant at 95% confidence level for morbidity response models. Both types of models were considered since the autocorrelations detected are only slightly significant in all cases.

5.1.3 Assessment of EBD due to ambient air pollution

Assessment of environmental burden of disease that can be attributed to ambient air pollution reveals that among various diseases, attributable fractions range between 0.05 and 0.15, the lowest being for all respiratory diseases, and the highest being for pneumonia, with corresponding PM2.5 attributable burdens of 547 and 509 cases each for the study period (2070-71).

5.2 Recommendations

In view of the finding of high emissions of $PM_{2.5}$ and NO_2 in Kathmandu Valley and their significant effects on respiratory health of the population, as demonstrated by statistical models and assessment of environmental burden of diseases, the following recommendations are made, which may be helpful to policy makers, concerned stakeholders and the public.

The likely main sources of $PM_{2.5}$, CO and NO_2 emissions are vehicular pollution from excessive traffic density in urban areas and old and poorly maintained vehicles, industrial pollution including brick kilns, fossil fuel burning including domestic use, and poor road maintenance. In view of these potential pollution sources within the valley, concerned policymakers should develop future policies and implement tasks in environment friendly ways. Several specific recommendations are made as follows:

- On-the-spot inspection of vehicles for emissions, particularly old vehicles and those are visibly emitting exhaust smoke is recommended.
- Maintenance of roads and traffic management within the valley are also very important factors and should be implemented effectively and on an ongoing basis.
- As regards industrial emissions, such as those from brick kilns, these operations should be shifted from densely populated areas to relatively remote areas wherever feasible.
- NO_2 pollution in ambient air is found at roughly equal levels in Lalitpur and Bhaktapur as in Kathmandu (comparing monthly highs), which suggests potential sources other than vehicles. Such sources need to be identified for possible reduction of levels.
- Considering differences in pollution levels at different time periods (morning, afternoon, evening, night), it was found that levels are relatively low after midnight and through to 6 AM, when they start to increase rapidly throughout the morning. Thus, it is recommended that for those who engage in outdoor exercise, it is best not to preference late morning (after 6 AM), particularly for the elderly population, which is most susceptible to respiratory and heart problems.
- Seasonal variation exists such that during dry winter months the ambient air is much more highly polluted than in hot wet months with adequate rainfall. Thus, people should be more careful during winter when pollution levels may increase significantly, and avoid frequent exposure to high traffic situations or late morning walks as much as possible.
- Compared to normal hours when mains electricity is available, ambient $PM_{2.5}$ is significantly high during scheduled power outage period. This can likely be attributed to use of more polluting sources of electricity like generators during scheduled power outage times. Use of generators should therefore be discouraged and other sources like solar power encouraged.
- Statistical models revealed that aged people (50 and above) are more seriously affected by $PM_{2.5}$, CO and NO_2 than the general populace. This indicates that elderly people should be more aware of the effects of ambient air pollution.
- The government should effectively implement an environment-friendly vehicle and transport policy.

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ANNEX I

Data Collection Sheet

Situation analysis of the ambient air pollution and respiratory health effect in Kathmandu Valley

Hospital Name:
Diseases Specific Morbidity Sheet:

SN	ADMISSION DATE	AGE	SEX	ADDRESS	DISEASE DIAGNOSIS	DISCHARGED DATE	REMARKS

Hospital Name:

Diseases Specific Mortality Sheet:

SN	ADMISSION DATE	AGE	SEX	ADDRESS	DISEASE DIAGNOSIS	DEATH DATE	Remark

Data Sheet for All Cause Mortality (Non-accidental) Hospital:

SN	ADMISSION DATE	AGE	SEX	ADDRESS	DISEASE	DEATH DATE

ANNEX II

Photos of monitoring stations and instruments

Putalishadak, Kathmandu

Mahalaxmisthan, Lalitpur

CO and NO_2 measurement instruments

Bhimsensthan, Bhaktpur

ANNEX III

Data Tables

Table A1: $PM_{2.5}$ scenario of Kathmandu Valley (for all three stations): Assessment of monthly variation

Month	Mean	N	SD	CV
Falgun 2070	79.5	6067	81.4	102.4
Chaitra 2070	70.2	7178	42.7	60.8
Baishak 2071	62	7268	39	63
Jestha 2071	42.3	7193	41.4	97.9
Ashad 2071	19.8	7674	12.9	65
Shrawan 2071	9.9	7368	8.5	85.7
Bhadra 2071	17.1	7391	30.8	180.3
Aswin 2071	15.5	7439	14.1	91
Kartik 2071	39	7200	26.9	68.9
Manshir 2071	82.2	6960	47.9	58.3
Poush 2071	78.4	7197	61.9	79
Magh 2071	85.5	6959	64.7	75.7
Overall	49.1	85894	52.1	106

Table A2: CO scenario of Kathmandu Valley (for all three stations): Assessment of monthly variation

Month	Mean	N	SD	CV
Falgun 2070	384.9	125973	913.3	2.4
Chaitra 2070	408.9	124771	1668.8	4.1
Baishak 2071	576.6	97774	1955.1	3.4
Jestha 2071	208.9	97327	907.7	4.4
Ashad 2071	476.8	116082	4581.5	9.6
Shrawan 2071	742.6	131750	6681.0	9.0
Bhadra 2071	311.4	133917	1079.2	3.5
Aswin 2071	151.4	133929	830.5	5.5
Kartik 2071	437.0	129600	1521.2	3.5

Manshir 2071	496.7	125272	1050.4	2.1
Poush 2071	626.5	129597	1329.2	2.1
Magh 2071	425.0	125281	909.9	2.1
Overall	438.2	1471273	2643.4	6.0

Table A3: $PM_{2.5}$ scenario of Kathmandu Valley (for all three stations): Between-stations monthly variation

Month		Station			
		Kathmandu	Bhaktapur	Lalitpur	Total
Falgun 2070	Mean	80.7	85.5	69.8	79.5
	N	1363	2793	1911	6067
	SD	49.0	108.4	44.7	81.4
Chaitra 2070	Mean	81.8	60.1	74.4	70.2
	N	1440	2859	2879	7178
	SD	47.8	36.9	43.1	42.7
Baishak 2071	Mean	74.8	54.2	63.0	62.0
	N	1488	2865	2915	7268
	SD	42.2	34.8	39.5	39.0
Jestha 2071	Mean	48.8	35.4	45.4	42.3
	N	1487	2734	2972	7193
	SD	23.7	22.7	57.6	41.4
Ashad 2071	Mean	27.7	13.7	22.0	19.8
	N	1536	3066	3072	7674
	SD	14.1	9.0	12.6	12.9
Shrawan 2071	Mean	16.3	5.6	10.9	9.9
	N	1488	2916	2964	7368
	SD	10.3	5.1	7.7	8.5
Bhadra 2071	Mean	24.7	14.6	15.8	17.1
	N	1439	2976	2976	7391
	SD	14.7	45.6	11.5	30.8
Aswin 2071	Mean	31.8	8.4	14.4	15.5
	N	1487	2976	2976	7439
	SD	16.2	7.0	11.5	14.1
Kartik 2071	Mean	52.0	42.2	29.3	39.0
	N	1440	2880	2880	7200
	SD	32.7	26.9	18.8	26.9
Manshir 2071	Mean	92.1	68.2	91.1	82.2
	N	1392	2784	2784	6960
	SD	44.2	37.1	55.3	47.9
Poush 2071	Mean	87.4	67.2	85.0	78.4
	N	1439	2878	2880	7197
	SD	57.1	53.3	70.1	61.9

Magh 2071	Mean	97.3	76.5	88.5	85.5
	N	1392	2783	2784	6959
	SD	54.4	66.2	66.7	64.7
Total	Mean	59.0	43.7	49.6	49.1
	N	17391	34510	33993	85894
	SD	46.7	53.9	52.0	52.1

Table A4: CO scenario of Kathmandu Valley (for all three stations): Between-stations monthly variation

Month	Station								
	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
Falgun 2070	401.0	41991	926.2	401.0	41991	926.2	352.7	41991	886.2
Chaitra 2070	1010.5	42979	2229.8	92.1	43200	1130.2	93.5	38592	1192.3
Baishak 2071	1262.7	44637	2739.8	0.4	44640	20.3	0.0	8497	0.0
Jestha 2071	456.7	44291	1296.8	0.0	44640	5.4	12.0	8396	290.8
Ashad 2071	1178.1	46079	7202.3	11.3	61291	371.2	42.3	8712	203.9
Shrawan 2071	1820.0	44628	10219.1	355.6	46074	4971.8	5.8	41048	91.3
Bhadra 2071	627.8	44639	1508.8	18.0	44639	329.9	288.4	44639	960.1
Aswin 2071	151.4	44643	830.5	151.4	44643	830.5	151.4	44643	830.5
Kartik 2071	672.0	43200	1309.9	442.4	43200	1872.6	196.6	43200	1267.6
Manshir 2071	857.8	41752	1183.8	304.8	41760	974.7	327.6	41760	873.3
Poush 2071	1150.7	43197	1534.6	350.6	43200	1135.4	378.1	43200	1115.3
Magh 2071	790.1	41761	1033.1	21.0	41760	284.6	463.7	41760	1018.5
Total	868.1	523797	3961.8	172.5	541038	1687.1	237.8	406438	951.7

Table A5: NO_2 scenario of Kathmandu Valley (for all three stations): Between-stations monthly variation

Month	Station								
	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
Falgun 2070	233.0	40223	745.9	472.6	39366	1414.4	341.5	39328	1315.0
Chaitra 2070	182.5	41933	649.2	57.9	41490	129.9	54.0	41638	103.6
Baishak 2071	267.9	43118	852.2	212.1	43996	1306.5	583.5	43654	1714.6
Jestha 2071	93.4	43750	162.2	173.9	42324	304.1	178.5	44394	306.0
Ashad 2071	63.4	46247	263.7	135.3	44640	531.6	135.3	44640	531.6
Shrawan 2071	31.4	43173	177.6	0.0	44639	0.0	66.4	42416	337.3
Bhadra 2071	39.8	43237	49.3	0.6	41083	11.1	0.0	42250	0.0
Aswin 2071	62.0	41934	82.4	77.9	43273	154.1	6.1	41760	33.2
Kartik 2071	190.1	43072	108.8	0.0	42197	0.0	44.7	81514	112.2
Manshir 2071	302.4	41760	144.5	150.7	41760	133.3	183.3	41760	117.0
Poush 2071	457.4	42227	106.4	103.4	42227	139.9	103.4	42227	139.9
Magh 2071	381.7	38881	145.9	717.6	38881	274.3	478.8	38880	323.1
Total	188.9	509555	418.8	169.4	505876	623.7	169.8	544461	666.9

Table A6: $PM_{2.5}$ assessment of 3-hourly intervals between stations

Period	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
AFTER MIDNIGHT (0-3 AM)	47.4	2172	36.3	32.3	4352	28.7	34.5	4246	34.1
BEFORE DAWN (3-6 AM)	48.2	2172	36.3	35	4333	32	42.8	4241	37.5
MORNING (6-9 AM)	83	2172	56.9	65.4	4301	60.6	78.1	4243	68.2
BEFORE NOON (9-12 Noon)	81.3	2173	57.9	55.1	4322	68.2	69.8	4241	67.9
AFTERNOON (12-3 PM)	43.7	2176	30.3	28.5	4305	43.1	36.4	4249	36.6

LATE AFTERNOON (3-6 PM)	43.5	2177	30.3	29.7	4265	39.6	39.7	4252	50.1
E V E N I N G (6-9 PM)	64.3	2178	47.3	52.9	4298	61.2	54	4261	48.8
NIGHT (9-12 MIDNIGHT)	60.4	2171	48.6	50.6	4334	67.2	41.2	4260	41.6
Total	59	17391	46.7	43.7	34510	53.9	49.6	33993	52

Table A7: CO assessment of 3-hourly intervals between stations

Three hourly interval	Station								
	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
AFTER MIDNIGHT (0-3 AM)	344.2	65515	884.1	60.5	67289	492.9	80.5	50495	401.1
BEFORE DAWN (3-6 AM)	318.7	65338	777.5	57.9	67139	425.2	66.3	50327	418.7
MORNING (6-9 AM)	1068.1	65336	1274.2	152.8	67141	654.2	289.0	50361	877.1
BEFORE NOON (9-12 NOON)	1009.3	65127	1839.0	320.2	67161	1950.0	405.8	50528	1453.2
AFTERNOON (12-3 PM)	1401.9	64963	10037.2	313.1	67301	4059.8	218.7	50768	1281.1
LATE AFTERNOON (3-6 PM)	889.5	65495	3739.0	149.9	67567	813.4	222.5	50994	878.0
EVENING (6-9 PM)	1256.9	65698	1559.4	219.0	67673	811.2	432.5	51150	1027.3
NIGHT (9-12 MIDNIGHT)	668.8	65626	1301.4	100.2	67627	530.9	187.8	51115	666.7
Total	869.2	523098	3964.3	171.7	538898	1687.8	238.2	405738	952.5

Table A8 : NO_2 assessment of 3-hourly intervals between stations

Period	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
AFTER MIDNIGHT (0-3 AM)	188.3	59202	217.9	191.1	54753	381.4	127.4	66400	238.9
BEFORE DAWN (3-6 AM)	195.6	49883	198.0	175.7	42157	303.7	136.6	56838	205.7
MORNING (6-9 AM)	258.5	47163	320.4	241.4	39474	516.0	242.0	54001	573.4
BEFORE NOON (9-12 NOON)	225.9	50274	646.0	215.6	51725	1105.3	224.1	57459	1114.0
AFTERNOON (12-3 PM)	177.3	60958	709.0	156.1	70524	785.0	186.8	68919	914.1
LATE AFTERNOON (3-6 PM)	165.4	70528	438.3	129.3	85075	667.9	155.5	79688	824.8
EVENING (6-9 PM)	210.1	73139	373.5	156.8	87586	497.4	179.7	82497	579.9
NIGHT (9-12 MIDNIGHT)	180.1	69535	214.8	149.7	74396	307.6	130.1	78477	288.6
Total	197.3	480682	429.2	168.9	505690	622.9	169.9	544279	667.0

Table A9: PM$_{2.5}$ scenario of Kathmandu Valley (for all the three stations): Assessment of daily variation

Month	Day	Mean	N	SD	Month	Day	Mean	N	SD
Falgun 2070	1	124.8	191	103.7		186	9.78	240	6.64
	2	144.1	191	135.4		187	9.75	240	8.22
	3	138.9	191	136.7		188	12.12	239	7.65
	4	111.0	190	84.1		189	23.15	240	11.73
	5	118.1	191	108.3		190	23.5	240	13.86
	6	89.6	191	93.7		191	20.65	240	12.16
	7	127.7	191	112.7		192	14.73	240	8.16
	8	119.6	191	83.5		193	23.29	240	11.93
	9	117.7	191	91.6		194	23.86	240	11.2
	10	101.3	191	64.2	Bhadra 2071	195	17.03	240	8.8
	11	72.7	191	50.0		196	14.95	240	9.2
	12	75.8	192	48.7		197	18.25	240	24.59
	13	114.5	190	100.1		198	11.18	240	6.89
	14	109.6	188	63.6		199	10.59	192	8.14
	15	122.0	191	91.0		200	8.81	240	8.51
	16	72.9	191	42.7		201	13.91	240	11.8
	17	59.1	179	39.7		202	16.48	240	13.59
	18	67.0	95	90.0		203	13.44	240	7.83
	19	44.3	153	26.3		204	16.05	240	9.78
	20	61.1	207	46.8		205	14.95	240	9.53
	21	57.6	239	28.0		206	15.23	240	9.23
	22	24.6	237	33.9		207	16.01	240	9.74
	23	50.3	238	42.4		208	13.75	240	7.89
	24	50.8	234	39.7		209	13.35	240	8.52
	25	50.7	239	54.4		210	15.75	240	10.45
	26	55.7	239	62.9		211	18.31	240	13.91
	27	49.2	240	47.9		212	39.33	240	156.43
	28	44.2	239	54.2		213	16.3	240	8.61
	29	37.6	237	38.4		214	19.75	240	12.61
	30	41.5	239	54.0		215	22.41	240	15.15
	Total	79.5	6067	81.4		216	20.76	240	11.74
Chaitra 2070	31	59.7	240	36.8		Total	17.06	7391	30.76
	32	68.0	240	37.3	Aswin 2071	217	19.38	240	13.87
	33	75.8	239	36.0		218	19.05	240	12.38
	34	69.7	238	46.8		219	15.23	239	11.67
	35	36.3	239	17.2		220	15.42	240	9.2
	36	57.2	239	29.8		221	15.05	240	11.84
	37	61.9	239	43.6		222	14.08	240	16.41
	38	43.7	239	21.0		223	14.83	240	16.94
	39	58.6	240	29.4		224	13.3	240	14.79
	40	81.9	240	40.7		225	11.11	240	10.72
	41	69.8	238	44.6		226	10.55	240	12.55
	42	63.2	239	39.6		227	16.41	240	14.34
	43	62.2	239	43.1		228	25.22	240	21.93
	44	58.8	239	33.3		229	23.03	240	17.51
	45	52.6	239	38.8		230	21.31	240	16.13

	46	52.6	240	31.9		231	15.93	240	14.91
	47	76.9	239	39.5		232	14.41	240	12.41
	48	88.7	240	55.4		233	15.86	240	14.78
	49	91.6	238	44.2		234	15.06	240	9.79
	50	101.2	240	51.7		235	14.67	240	10.08
	51	50.1	240	35.5		236	14.18	240	11.76
	52	72.7	239	34.9		237	14.14	240	11.33
	53	93.8	240	34.7		238	13	240	11.89
	54	80.6	240	47.6		239	13.65	240	12.05
	55	53.9	239	33.7		240	14.5	240	13.84
	56	68.0	238	36.0		241	14.12	240	16.83
	57	77.1	240	36.4		242	15.03	240	15.13
	58	99.1	240	40.5		243	18.93	240	21.09
	59	82.2	238	48.4		244	14.09	240	10.87
	60	98.6	240	47.2		245	12.15	240	9.21
	Total	70.2	7178	42.7		246	13.3	240	8.87
Baishak 2071	61	87.6	238	59.8		247	12.6	240	7.39
	62	58.7	238	37.7		Total	15.47	7439	14.07
	63	84.0	269	53.3		248	15.24	240	11.39
	64	73.6	206	35.4		249	19.74	240	11.97
	65	74.5	238	43.1		250	19.85	240	9.87
	66	73.3	239	52.4		251	20.15	240	12.62
	67	49.4	239	31.8		252	20.9	240	12.31
	68	61.9	239	38.3		253	22.73	240	15.9
	69	71.4	240	36.8		254	21.74	240	11.57
	70	79.1	238	53.1		255	20.52	240	12.61
	71	58.0	239	30.2		256	18.2	240	8.64
	72	61.8	239	31.2		257	19.81	240	11.07
	73	57.8	179	41.1		258	24.25	240	12.54
	74	74.0	238	35.3	Kartik 2071	259	42.6	240	29.79
	75	63.1	240	44.0		260	50.87	240	30.81
	76	73.9	238	42.0		261	52.49	240	31.62
	77	70.6	239	30.8		262	47.29	240	31.94
	78	78.1	239	42.3		263	49.89	240	15.84
	79	49.2	239	19.8		264	51.51	240	29.2
	80	58.5	239	25.5		265	42.71	240	19.48
	81	51.2	238	23.6		266	42.08	240	16.75
	82	55.3	238	32.1		267	47.88	240	19.32
	83	57.2	239	31.8		268	44.55	240	21.01
	84	46.3	239	28.1		269	45.23	240	20.75
	85	46.1	238	21.5		270	44.36	240	20.15
	86	59.6	240	34.8		271	38.45	240	19.17
	87	48.0	239	26.9		272	54.68	240	24.01
	88	50.0	238	31.6		273	50.52	240	23.91
	89	52.0	237	34.6		274	52.89	240	19.4
	90	49.9	198	31.2		275	56.7	240	22.45
	91	40.3	211	28.6		276	55.76	240	26.21
	Total	62.0	7268	39.0		277	76.52	240	48.92
Jestha 2071	92	37.4	236	45.7		Total	39	7200	26.85
	93	37.0	238	17.3		278	73.04	240	35.12

	94	46.2	240	35.9		279	80.29	240	27.92
	95	87.2	237	172.7		280	95.61	240	41.49
	96	61.8	239	40.2		281	80.03	240	38.07
	97	73.9	237	47.7		282	74.99	240	32.81
	98	48.8	222	33.1		283	78.89	240	37.56
	99	37.8	240	21.5		284	64.12	240	25.09
	100	49.7	238	26.3		285	65.03	240	31.15
	101	47.8	200	22.2		286	77.36	240	26.19
	102	38.8	206	22.2		287	77.84	240	28.67
	103	24.8	224	19.8		288	74.93	240	29.93
	104	39.3	197	22.4		289	80.04	240	30.52
	105	30.1	208	20.5		290	86.17	240	35.17
	106	28.8	208	11.3	Manshir 2071	291	134.08	240	64.73
	107	31.7	230	17.4		292	164.87	240	80.57
	108	22.7	240	19.3		293	107.28	240	49.16
	109	27.9	240	15.3		294	99.2	240	51.7
	110	27.8	239	16.0		295	73.73	240	34.88
	111	35.4	239	15.4		296	73.5	240	32.28
	112	48.9	239	26.0		297	69.66	240	32.22
	113	46.0	239	15.0		298	59.51	240	35.93
	114	63.5	240	15.8		299	68.07	240	39.47
	115	49.1	238	19.1		300	61.74	240	28.2
	116	49.6	240	12.3		301	82.02	240	51.51
	117	37.1	240	10.9		302	75.45	240	48.02
	118	42.0	240	14.1		303	79.85	240	64.95
	119	30.6	239	11.5		304	113.11	240	54.97
	120	40.0	240	19.5		305	68.36	240	34.77
	121	33.4	240	15.4		306	44.09	240	33.33
	122	31.8	240	11.9		Total	82.17	6960	47.88
	Total	42.3	7193	41.4		307	33.89	240	21.52
Ashad 2071	123	33.4	239	12.5		308	62.38	240	51.75
	124	32.7	240	12.0		309	69.13	240	48.38
	125	17.8	240	9.5		310	75.38	240	59.56
	126	21.5	240	9.2		311	72.77	240	49.65
	127	21.5	240	11.1		312	65.17	240	49.71
	128	16.2	240	10.5		313	78.22	240	43.49
	129	13.1	240	10.7		314	71.04	239	37.92
	130	12.0	240	7.8		315	72.16	240	40.96
	131	22.5	240	10.9		316	71.8	240	47.52
	132	29.1	239	12.9		317	57.96	240	42.59
	133	32.7	240	12.8		318	52.38	240	35.24
	134	25.2	240	12.3		319	65.71	240	36.65
	135	22.1	240	11.8		320	71.97	240	52.97
	136	21.9	240	11.9		321	74.1	240	49.13
	137	28.1	240	13.0		322	89.68	239	58.74
	138	26.5	239	15.5	Poush 2071	323	192.61	239	146.66
	139	15.4	240	11.8		324	120.72	240	64.53
	140	13.0	240	7.3		325	98.46	240	56.18
	141	12.2	240	8.2		326	79.53	240	50.8
	142	11.8	240	11.4		327	43.85	240	29.98

	143	12.4	240	9.2		328	59.31	240	30.22
	144	12.0	240	7.5		329	60.6	240	43.21
	145	23.1	239	7.9		330	55.5	240	40.04
	146	21.1	240	9.4		331	79.53	240	49.53
	147	16.5	240	10.1		332	89.26	240	57.08
	148	26.9	240	14.4		333	100.15	240	62.29
	149	22.0	240	9.3		334	102.06	240	62.61
	150	25.9	240	11.9		335	99.77	240	65.37
	151	15.3	240	9.9		336	86.19	240	57.27
	152	10.6	239	6.7		Total	78.36	7197	61.91
	153	9.8	240	8.5		337	77.35	240	47.2
	154	9.3	239	8.5		338	76.58	240	48.26
	Total	19.8	7674	12.9		339	79.16	240	54.26
	155	8.1	229	8.6		340	74.75	240	49.61
	156	8.2	188	6.3		341	87.88	240	68.37
	157	6.7	240	5.4		342	77.9	240	58.01
	158	8.7	239	7.8		343	99.18	240	72.76
	159	7.6	239	7.6		344	91.54	240	70.32
	160	9.5	239	10.0		345	74.26	240	45.58
	161	11.4	240	9.9		346	94.05	240	89.42
	162	7.1	240	5.7		347	76.52	240	56.97
	163	10.0	239	11.7		348	124.74	240	52.95
	164	10.0	240	7.9		349	125.32	240	79.32
	165	8.9	240	6.8		350	82.13	240	57.38
	166	12.0	239	9.2		351	100.19	240	68
	167	7.6	240	6.4		352	103.78	240	64.72
	168	8.0	240	8.2		353	94.97	239	58.27
Shrawan 2071	169	9.2	239	7.7	Magh 2071	354	114.52	240	58.31
	170	10.0	240	8.2		355	106.48	240	58.96
	171	9.9	240	9.6		356	105.21	240	89.64
	172	11.3	240	9.3		357	50	240	39.11
	173	9.8	240	8.0		358	68.96	240	55.59
	174	10.2	240	7.7		359	80.33	240	49.83
	175	8.9	240	7.6		360	83.07	240	85.29
	176	10.1	239	6.7		361	63.18	240	50.24
	177	9.1	240	6.8		362	65.96	240	51.99
	178	10.5	240	5.9		363	59.25	240	44.52
	179	8.6	240	6.5		364	61.44	240	48.28
	180	10.5	240	13.0		365	79.83	240	82.22
	181	12.4	240	7.1		Total	85.47	6959	64.69
	182	10.6	240	6.8					
	183	10.4	240	7.9					
	184	14.4	238	9.8					
	185	16.4	240	9.7					
	Total	9.9	7368	8.5					

Month	Day	Mean	N	SD	Month	Day	Mean	N	SD
Falgun 2070	1	124.8	191	103.7		186	9.78	240	6.64
	2	144.1	191	135.4		187	9.75	240	8.22
	3	138.9	191	136.7		188	12.12	239	7.65
	4	111.0	190	84.1		189	23.15	240	11.73
	5	118.1	191	108.3		190	23.5	240	13.86

	6	89.6	191	93.7
	7	127.7	191	112.7
	8	119.6	191	83.5
	9	117.7	191	91.6
	10	101.3	191	64.2
	11	72.7	191	50.0
	12	75.8	192	48.7
	13	114.5	190	100.1
	14	109.6	188	63.6
	15	122.0	191	91.0
	16	72.9	191	42.7
	17	59.1	179	39.7
	18	67.0	95	90.0
	19	44.3	153	26.3
	20	61.1	207	46.8
	21	57.6	239	28.0
	22	24.6	237	33.9
	23	50.3	238	42.4
	24	50.8	234	39.7
	25	50.7	239	54.4
	26	55.7	239	62.9
	27	49.2	240	47.9
	28	44.2	239	54.2
	29	37.6	237	38.4
	30	41.5	239	54.0
	Total	79.5	6067	81.4
Chaitra 2070	31	59.7	240	36.8
	32	68.0	240	37.3
	33	75.8	239	36.0
	34	69.7	238	46.8
	35	36.3	239	17.2
	36	57.2	239	29.8
	37	61.9	239	43.6
	38	43.7	239	21.0
	39	58.6	240	29.4
	40	81.9	240	40.7
	41	69.8	238	44.6
	42	63.2	239	39.6
	43	62.2	239	43.1
	44	58.8	239	33.3
	45	52.6	239	38.8
	46	52.6	240	31.9
	47	76.9	239	39.5
	48	88.7	240	55.4
	49	91.6	238	44.2
	50	101.2	240	51.7
	51	50.1	240	35.5
	52	72.7	239	34.9
	53	93.8	240	34.7
	54	80.6	240	47.6

Bhadra 2071	191	20.65	240	12.16
	192	14.73	240	8.16
	193	23.29	240	11.93
	194	23.86	240	11.2
	195	17.03	240	8.8
	196	14.95	240	9.2
	197	18.25	240	24.59
	198	11.18	240	6.89
	199	10.59	192	8.14
	200	8.81	240	8.51
	201	13.91	240	11.8
	202	16.48	240	13.59
	203	13.44	240	7.83
	204	16.05	240	9.78
	205	14.95	240	9.53
	206	15.23	240	9.23
	207	16.01	240	9.74
	208	13.75	240	7.89
	209	13.35	240	8.52
	210	15.75	240	10.45
	211	18.31	240	13.91
	212	39.33	240	156.43
	213	16.3	240	8.61
	214	19.75	240	12.61
	215	22.41	240	15.15
	216	20.76	240	11.74
	Total	17.06	7391	30.76
Aswin 2071	217	19.38	240	13.87
	218	19.05	240	12.38
	219	15.23	239	11.67
	220	15.42	240	9.2
	221	15.05	240	11.84
	222	14.08	240	16.41
	223	14.83	240	16.94
	224	13.3	240	14.79
	225	11.11	240	10.72
	226	10.55	240	12.55
	227	16.41	240	14.34
	228	25.22	240	21.93
	229	23.03	240	17.51
	230	21.31	240	16.13
	231	15.93	240	14.91
	232	14.41	240	12.41
	233	15.86	240	14.78
	234	15.06	240	9.79
	235	14.67	240	10.08
	236	14.18	240	11.76
	237	14.14	240	11.33
	238	13	240	11.89
	239	13.65	240	12.05

	55	53.9	239	33.7
	56	68.0	238	36.0
	57	77.1	240	36.4
	58	99.1	240	40.5
	59	82.2	238	48.4
	60	98.6	240	47.2
	Total	70.2	7178	42.7
Baishak 2071	61	87.6	238	59.8
	62	58.7	238	37.7
	63	84.0	269	53.3
	64	73.6	206	35.4
	65	74.5	238	43.1
	66	73.3	239	52.4
	67	49.4	239	31.8
	68	61.9	239	38.3
	69	71.4	240	36.8
	70	79.1	238	53.1
	71	58.0	239	30.2
	72	61.8	239	31.2
	73	57.8	179	41.1
	74	74.0	238	35.3
	75	63.1	240	44.0
	76	73.9	238	42.0
	77	70.6	239	30.8
	78	78.1	239	42.3
	79	49.2	239	19.8
	80	58.5	239	25.5
	81	51.2	238	23.6
	82	55.3	238	32.1
	83	57.2	239	31.8
	84	46.3	239	28.1
	85	46.1	238	21.5
	86	59.6	240	34.8
	87	48.0	239	26.9
	88	50.0	238	31.6
	89	52.0	237	34.6
	90	49.9	198	31.2
	91	40.3	211	28.6
	Total	62.0	7268	39.0
Jestha 2071	92	37.4	236	45.7
	93	37.0	238	17.3
	94	46.2	240	35.9
	95	87.2	237	172.7
	96	61.8	239	40.2
	97	73.9	237	47.7
	98	48.8	222	33.1
	99	37.8	240	21.5
	100	49.7	238	26.3
	101	47.8	200	22.2
	102	38.8	206	22.2

	240	14.5	240	13.84
	241	14.12	240	16.83
	242	15.03	240	15.13
	243	18.93	240	21.09
	244	14.09	240	10.87
	245	12.15	240	9.21
	246	13.3	240	8.87
	247	12.6	240	7.39
	Total	15.47	7439	14.07
Kartik 2071	248	15.24	240	11.39
	249	19.74	240	11.97
	250	19.85	240	9.87
	251	20.15	240	12.62
	252	20.9	240	12.31
	253	22.73	240	15.9
	254	21.74	240	11.57
	255	20.52	240	12.61
	256	18.2	240	8.64
	257	19.81	240	11.07
	258	24.25	240	12.54
	259	42.6	240	29.79
	260	50.87	240	30.81
	261	52.49	240	31.62
	262	47.29	240	31.94
	263	49.89	240	15.84
	264	51.51	240	29.2
	265	42.71	240	19.48
	266	42.08	240	16.75
	267	47.88	240	19.32
	268	44.55	240	21.01
	269	45.23	240	20.75
	270	44.36	240	20.15
	271	38.45	240	19.17
	272	54.68	240	24.01
	273	50.52	240	23.91
	274	52.89	240	19.4
	275	56.7	240	22.45
	276	55.76	240	26.21
	277	76.52	240	48.92
	Total	39	7200	26.85
	278	73.04	240	35.12
	279	80.29	240	27.92
	280	95.61	240	41.49
	281	80.03	240	38.07
	282	74.99	240	32.81
	283	78.89	240	37.56
	284	64.12	240	25.09
	285	65.03	240	31.15
	286	77.36	240	26.19
	287	77.84	240	28.67

	103	24.8	224	19.8	Manshir 2071	288	74.93	240	29.93
	104	39.3	197	22.4		289	80.04	240	30.52
	105	30.1	208	20.5		290	86.17	240	35.17
	106	28.8	208	11.3		291	134.08	240	64.73
	107	31.7	230	17.4		292	164.87	240	80.57
	108	22.7	240	19.3		293	107.28	240	49.16
	109	27.9	240	15.3		294	99.2	240	51.7
	110	27.8	239	16.0		295	73.73	240	34.88
	111	35.4	239	15.4		296	73.5	240	32.28
	112	48.9	239	26.0		297	69.66	240	32.22
	113	46.0	239	15.0		298	59.51	240	35.93
	114	63.5	240	15.8		299	68.07	240	39.47
	115	49.1	238	19.1		300	61.74	240	28.2
	116	49.6	240	12.3		301	82.02	240	51.51
	117	37.1	240	10.9		302	75.45	240	48.02
	118	42.0	240	14.1		303	79.85	240	64.95
	119	30.6	239	11.5		304	113.11	240	54.97
	120	40.0	240	19.5		305	68.36	240	34.77
	121	33.4	240	15.4		306	44.09	240	33.33
	122	31.8	240	11.9		Total	82.17	6960	47.88
	Total	42.3	7193	41.4	Poush 2071	307	33.89	240	21.52
Ashad 2071	123	33.4	239	12.5		308	62.38	240	51.75
	124	32.7	240	12.0		309	69.13	240	48.38
	125	17.8	240	9.5		310	75.38	240	59.56
	126	21.5	240	9.2		311	72.77	240	49.65
	127	21.5	240	11.1		312	65.17	240	49.71
	128	16.2	240	10.5		313	78.22	240	43.49
	129	13.1	240	10.7		314	71.04	239	37.92
	130	12.0	240	7.8		315	72.16	240	40.96
	131	22.5	240	10.9		316	71.8	240	47.52
	132	29.1	239	12.9		317	57.96	240	42.59
	133	32.7	240	12.8		318	52.38	240	35.24
	134	25.2	240	12.3		319	65.71	240	36.65
	135	22.1	240	11.8		320	71.97	240	52.97
	136	21.9	240	11.9		321	74.1	240	49.13
	137	28.1	240	13.0		322	89.68	239	58.74
	138	26.5	239	15.5		323	192.61	239	146.66
	139	15.4	240	11.8		324	120.72	240	64.53
	140	13.0	240	7.3		325	98.46	240	56.18
	141	12.2	240	8.2		326	79.53	240	50.8
	142	11.8	240	11.4		327	43.85	240	29.98
	143	12.4	240	9.2		328	59.31	240	30.22
	144	12.0	240	7.5		329	60.6	240	43.21
	145	23.1	239	7.9		330	55.5	240	40.04
	146	21.1	240	9.4		331	79.53	240	49.53
	147	16.5	240	10.1		332	89.26	240	57.08
	148	26.9	240	14.4		333	100.15	240	62.29
	149	22.0	240	9.3		334	102.06	240	62.61
	150	25.9	240	11.9		335	99.77	240	65.37
	151	15.3	240	9.9		336	86.19	240	57.27

	152	10.6	239	6.7		Total	78.36	7197	61.91
	153	9.8	240	8.5	Magh 2071	337	77.35	240	47.2
	154	9.3	239	8.5		338	76.58	240	48.26
	Total	19.8	7674	12.9		339	79.16	240	54.26
Shrawan 2071	155	8.1	229	8.6		340	74.75	240	49.61
	156	8.2	188	6.3		341	87.88	240	68.37
	157	6.7	240	5.4		342	77.9	240	58.01
	158	8.7	239	7.8		343	99.18	240	72.76
	159	7.6	239	7.6		344	91.54	240	70.32
	160	9.5	239	10.0		345	74.26	240	45.58
	161	11.4	240	9.9		346	94.05	240	89.42
	162	7.1	240	5.7		347	76.52	240	56.97
	163	10.0	239	11.7		348	124.74	240	52.95
	164	10.0	240	7.9		349	125.32	240	79.32
	165	8.9	240	6.8		350	82.13	240	57.38
	166	12.0	239	9.2		351	100.19	240	68
	167	7.6	240	6.4		352	103.78	240	64.72
	168	8.0	240	8.2		353	94.97	239	58.27
	169	9.2	239	7.7		354	114.52	240	58.31
	170	10.0	240	8.2		355	106.48	240	58.96
	171	9.9	240	9.6		356	105.21	240	89.64
	172	11.3	240	9.3		357	50	240	39.11
	173	9.8	240	8.0		358	68.96	240	55.59
	174	10.2	240	7.7		359	80.33	240	49.83
	175	8.9	240	7.6		360	83.07	240	85.29
	176	10.1	239	6.7		361	63.18	240	50.24
	177	9.1	240	6.8		362	65.96	240	51.99
	178	10.5	240	5.9		363	59.25	240	44.52
	179	8.6	240	6.5		364	61.44	240	48.28
	180	10.5	240	13.0		365	79.83	240	82.22
	181	12.4	240	7.1		Total	85.47	6959	64.69
	182	10.6	240	6.8					
	183	10.4	240	7.9					
	184	14.4	238	9.8					
	185	16.4	240	9.7					
	Total	9.9	7368	8.5					

Table A10: CO scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Month	Day	Mean	N	SD	Month	Day	Mean	N	SD
Falgun 2070	1	666.6	4320	1025.3	Bhadra 2071	186	330.3	4320	792.0
	2	291.0	4320	748.8		187	562.2	4320	2501.6
	3	436.9	4322	955.9		188	356.0	4320	1032.7
	4	575.7	4320	947.6		189	404.2	4320	1188.4
	5	0.0	4317	0.0		190	145.3	4320	645.9
	6	0.0	4317	0.0		191	126.2	4320	631.0
	7	160.6	4320	490.0		192	33.1	4320	226.8
	8	438.4	4317	956.5		193	446.6	4320	1695.6
	9	574.1	4320	947.6		194	170.2	4320	672.7
	10	574.6	3288	1059.4		195	224.8	4320	834.4
	11	574.9	4320	947.6		196	147.1	4320	693.4

	12	504.9	4320	931.6		197	147.1	4320	622.8
	13	0.0	4320	0.0		198	288.4	4320	1011.1
	14	0.0	4320	0.0		199	35.5	4320	260.7
	15	166.2	4320	591.9		200	225.6	4320	958.9
	16	5.6	4320	79.7		201	159.0	4320	676.7
	17	0.0	4320	0.0		202	256.0	4320	728.8
	18	438.1	4320	956.3		203	518.4	4320	1244.0
	19	599.9	4134	960.6		204	543.3	4320	1357.8
	20	235.4	4320	793.4		205	345.6	4320	1128.9
	21	955.0	4320	1746.4		206	62.0	4320	325.6
	22	898.7	2106	1209.2		207	316.5	4320	876.7
	23	1223.7	4320	1456.1		208	297.4	4320	793.6
	24	525.1	4134	1070.5		209	548.7	4320	1379.2
	25	0.0	4320	0.0		210	314.3	4320	827.6
	26	0.0	4320	0.0		211	529.0	4320	1226.8
	27	0.0	4320	0.0		212	295.8	4320	754.6
	28	436.5	4320	956.0		213	224.8	4320	646.7
	29	1012.2	4320	1144.2		214	877.8	4320	1698.9
	30	576.0	4318	947.7		215	721.2	4320	1603.4
	Total	384.9	125973	913.3		216	0.0	4317	0.0
Chaitra 2070	31	309.0	4320	817.1		Total	311.4	133917	1079.2
	32	344.0	4320	752.2	Aswin 2071	217	78.7	4323	367.2
	33	852.9	4320	2319.2		218	680.6	4320	1562.6
	34	261.6	4320	1285.0		219	664.7	4320	1391.0
	35	134.6	4320	548.8		220	318.1	4320	855.1
	36	449.3	4320	1305.7		221	365.8	4320	853.0
	37	425.4	4320	1237.0		222	606.7	4320	1186.8
	38	505.2	4320	1773.8		223	129.6	4320	367.8
	39	751.1	4320	2601.9		224	1021.8	4320	2173.2
	40	467.6	4329	1225.5		225	82.0	4317	386.2
	41	804.7	4320	4242.1		226	45.3	4320	257.4
	42	403.8	4330	1175.7		227	39.8	4320	226.4
	43	277.2	4320	1002.5		228	83.5	4320	318.4
	44	573.3	4320	1597.0		229	573.3	4320	2562.7
	45	130.7	4320	561.5		230	4.0	4320	79.7
	46	0.0	4320	0.0		231	0.0	4320	0.0
	47	106.3	4351	872.3		232	0.0	4320	0.0
	48	166.8	4319	654.6		233	0.0	4320	0.0
	49	229.4	4162	940.8		234	0.0	4320	0.0
	50	425.7	4564	1315.4		235	0.0	4326	0.0
	51	521.4	4320	1661.8		236	0.0	4323	0.0
	52	417.2	4320	1043.1		237	0.0	4320	0.0
	53	168.3	4076	801.5		238	0.0	4320	0.0
	54	610.1	4219	3751.4		239	0.0	4320	0.0
	55	258.7	4320	886.9		240	0.0	4320	0.0
	56	529.0	4320	1435.6		241	0.0	4320	0.0
	57	277.2	3168	1085.3		242	0.0	4320	0.0
	58	298.5	3157	1116.4		243	0.0	4320	0.0
	59	339.4	3168	892.1		244	0.0	4320	0.0
	60	1394.0	3168	2544.7		245	0.0	4320	0.0

	Total	408.9	124771	1668.8		246	0.0	4320	0.0
Baishak 2071	61	894.5	2880	1506.2		247	0.0	4320	0.0
	62	767.1	3027	1567.0		Total	151.4	133929	830.5
	63	749.7	3166	1855.3	Kartik 2071	248	358.6	4320	1484.4
	64	498.4	3168	1241.7		249	672.2	4320	1653.7
	65	532.7	3168	1267.1		250	1140.8	4320	4549.6
	66	278.7	3168	782.6		251	967.2	4320	4879.1
	67	448.5	3168	1113.8		252	279.9	4320	924.5
	68	581.9	3168	1459.2		253	11.9	4320	137.8
	69	622.4	3168	1331.1		254	2.4	4321	52.2
	70	534.9	3168	1315.2		255	156.9	4320	806.5
	71	369.0	3168	974.1		256	324.7	4320	981.5
	72	639.4	3168	1373.8		257	449.3	4320	742.9
	73	360.3	3168	865.9		258	561.4	4320	1038.3
	74	1073.8	3168	3395.0		259	434.7	4320	676.0
	75	641.5	3168	1541.0		260	493.8	4320	878.7
	76	822.3	3168	2199.8		261	494.6	4320	755.4
	77	597.1	3168	1481.3		262	371.1	4320	657.1
	78	672.3	3168	1611.8		263	750.3	4319	962.9
	79	318.5	3167	916.8		264	367.9	4320	807.5
	80	185.1	3168	590.8		265	438.1	4320	946.4
	81	986.7	3168	2736.2		266	341.1	4320	744.0
	82	2161.6	3166	6643.5		267	474.2	4320	821.3
	83	502.0	3168	2209.4		268	422.5	4320	746.1
	84	375.5	3168	998.5		269	79.0	4320	324.8
	85	302.5	3168	898.4		270	475.0	4320	883.4
	86	383.8	3168	1072.0		271	360.7	4320	728.5
	87	225.9	3168	736.9		272	349.9	4320	897.3
	88	468.8	3168	1233.3		273	398.9	4320	958.8
	89	436.6	3168	2013.3		274	412.9	4320	796.1
	90	361.4	3168	1131.8		275	300.6	4320	635.9
	91	120.7	3168	486.1		276	313.3	4320	1089.5
	Total	576.6	97774	1955.1		277	907.5	4320	1467.0
Jestha 2071	92	156.0	2885	674.7		Total	437.0	129600	1521.2
	93	421.3	3044	1136.9	Manshir 2071	278	587.4	4312	768.8
	94	120.7	3168	460.7		279	446.3	4320	886.9
	95	473.5	3168	1179.1		280	562.4	4320	948.2
	96	740.6	3168	1276.4		281	494.3	4320	843.1
	97	755.7	3168	1301.0		282	298.4	4320	701.8
	98	175.3	3168	632.6		283	233.2	4320	548.4
	99	288.5	2814	845.6		284	459.3	4320	1717.5
	100	440.9	3168	1026.7		285	58.6	4320	313.5
	101	62.9	3168	271.8		286	190.0	4320	778.4
	102	201.3	3168	737.8		287	17.8	4320	143.6
	103	641.2	3168	1717.1		288	48.0	4320	280.6
	104	401.2	3168	1285.0		289	30.0	4320	190.9
	105	198.8	3168	737.1		290	247.6	4320	1072.3
	106	139.5	3168	529.4		291	750.9	4320	1669.2
	107	264.6	3168	902.3		292	794.9	4320	1187.7
	108	14.8	3168	144.5		293	733.4	4320	1061.3

	109	194.8	3168	565.8		294	667.9	4320	982.5
	110	290.2	3168	976.5		295	557.1	4320	913.9
	111	483.1	3048	2632.8		296	744.8	4320	981.3
	112	0.0	3168	0.0		297	485.8	4320	799.0
	113	20.2	3168	356.8		298	608.3	4320	944.0
	114	12.3	3168	312.3		299	779.0	4320	1130.9
	115	0.0	3168	0.0		300	601.1	4320	1039.7
	116	0.0	3168	0.0		301	729.7	4320	1062.7
	117	0.0	3168	0.0		302	887.1	4320	1171.6
	118	0.0	3168	0.0		303	645.9	4320	1560.3
	119	0.0	3168	0.0		304	601.4	4320	1438.1
	120	0.0	3168	0.0		305	650.7	4320	1290.0
	121	0.0	3168	0.0		306	494.1	4320	917.3
	122	0.0	3168	0.0		Total	496.7	125272	1050.4
	Total	208.9	97327	907.7	Poush 2071	307	424.9	4320	907.7
Ashad 2071	123	1.6	2880	85.3		308	693.6	4320	1100.2
	124	83.7	3052	457.3		309	870.2	4320	1154.4
	125	527.0	3168	5227.1		310	1163.0	4320	1263.2
	126	1282.3	3168	11885.2		311	598.7	4320	871.1
	127	174.2	3168	607.9		312	660.8	4320	984.1
	128	149.6	3168	493.3		313	710.6	4320	1000.1
	129	233.8	3168	597.0		314	717.5	4320	982.0
	130	21.3	3168	219.0		315	583.1	4320	1542.2
	131	27.6	3157	217.8		316	797.3	4320	2338.5
	132	351.3	3168	2625.0		317	350.7	4320	1224.0
	133	379.1	3168	1037.0		318	1114.5	4320	2394.7
	134	507.8	3168	1102.8		319	782.7	4320	1651.1
	135	418.5	3168	1106.0		320	798.6	4320	996.8
	136	222.6	3168	706.1		321	751.7	4320	1012.1
	137	531.3	3168	1281.3		322	1376.2	4319	1524.4
	138	705.1	3168	1584.6		323	1747.1	4319	1924.1
	139	435.9	3168	1103.8		324	330.8	4320	1047.3
	140	359.6	3168	1055.7		325	231.1	4320	919.9
	141	803.5	3168	2225.9		326	280.4	4320	1006.7
	142	605.8	3168	1324.1		327	282.8	4320	851.7
	143	320.2	3168	949.6		328	289.4	4320	746.9
	144	336.0	3989	906.8		329	215.5	4320	693.4
	145	379.4	4608	1042.7		330	309.6	4320	737.6
	146	458.2	4608	1058.4		331	361.0	4320	1472.7
	147	512.2	4608	1394.2		332	563.8	4320	2003.5
	148	353.0	4510	1053.4		333	533.3	4320	1133.5
	149	501.7	4608	1492.9		334	411.7	4319	818.9
	150	180.4	4608	601.6		335	338.5	4320	719.1
	151	380.6	4608	1067.6		336	505.4	4320	926.4
	152	2355.6	4608	19224.5		Total	626.5	129597	1329.2
	153	702.8	4608	3104.6	Magh 2071	337	286.7	4321	620.6
	154	308.4	4606	959.6		338	252.6	4320	577.5
	Total	476.8	116082	4581.5		339	337.7	4320	720.1
Shrawan 2071	155	509.1	4408	1302.5		340	348.3	4320	700.9
	156	729.2	3168	1593.9		341	451.4	4320	1245.9

	157	163.6	3168	461.8		342	503.1	4320	1523.1
	158	1138.9	3167	1821.1		343	792.5	4320	1446.2
	159	6095.8	3168	21419.0		344	487.2	4320	909.0
	160	3841.4	3168	25658.4		345	502.8	4320	855.0
	161	473.7	3168	919.9		346	326.8	4320	678.2
	162	709.7	3168	1551.6		347	304.8	4320	639.6
	163	682.6	3168	1571.9		348	491.1	4320	876.4
	164	298.2	3168	697.5		349	806.3	4320	1238.6
	165	568.5	3168	1341.1		350	669.8	4320	1110.3
	166	1467.4	3168	9294.6		351	398.1	4320	775.2
	167	471.5	3168	1139.9		352	208.9	4320	532.5
	168	3351.0	3168	22581.2		353	428.1	4320	808.8
	169	447.1	3168	1051.0		354	491.1	4320	867.7
	170	625.5	3168	1355.7		355	503.1	4320	851.1
	171	332.7	3168	739.2		356	337.7	4320	780.4
	172	503.9	3019	912.4		357	300.8	4320	640.8
	173	837.8	4517	5006.7		358	347.0	4320	719.7
	174	469.4	5759	1382.1		359	399.2	4320	803.9
	175	388.0	5760	1136.2		360	344.0	4320	792.7
	176	396.6	5760	1141.1		361	373.7	4320	748.9
	177	405.9	5760	1274.6		362	612.3	4320	1130.8
	178	126.2	5760	420.0		363	371.3	4320	810.2
	179	172.7	5760	613.6		364	337.9	4320	724.8
	180	330.8	5760	2576.3		365	309.6	4320	952.4
	181	341.7	5760	1227.6		Total	425.0	125281	909.9
	182	339.9	5760	1041.7					
	183	472.7	5760	1417.8					
	184	372.3	5760	1001.1					
	185	91.4	5760	363.1					
	Total	742.6	131750	6681.0					

Table A11: NO_2 scenario of Kathmandu valley (for all the three stations): Assessment of daily variation

Month	Day	Mean	N	SD	Month	Day	Mean	N	SD
Falgun 2070	1	793.4	2835	1027.18	Bhadra 2071	186	10.5	2660	30.7
	2	680.0	4320	1251.3		187	6.5	4492	24.7
	3	591.2	2913	1147.3		188	1.0	4239	9.9
	4	519.4	4320	977.2		189	7.3	4320	26.1
	5	3386.1	3459	5622.0		190	18.9	4320	39.3
	6	8.7	2959	37.4		191	6.5	4320	24.6
	7	37.1	4386	76.1		192	4.0	4320	19.6
	8	76.9	4122	339.8		193	13.0	4320	33.6
	9	227.9	4461	245.5		194	16.8	4319	38.8
	10	323.2	3183	656.9		195	10.1	4320	30.1
	11	99.2	4355	140.6		196	11.3	4320	31.7
	12	183.2	4544	181.3		197	12.2	4320	32.8
	13	173.2	4392	164.9		198	8.0	4320	28.8

	14	199.4	4375	138.0
	15	125.2	4320	139.6
	16	223.3	4694	276.9
	17	188.0	2384	167.3
	18	263.2	4176	143.7
	19	244.8	4116	165.1
	20	256.5	4320	219.5
	21	149.5	3862	199.0
	22	35.8	1985	321.2
	23	40.9	4320	116.9
	24	108.9	4196	205.3
	25	350.9	4320	244.9
	26	389.0	4320	475.8
	27	286.7	4320	233.4
	28	336.6	4320	283.9
	29	303.9	4320	279.6
	30	314.5	4320	343.9
	Total	348.2	118917	1196.6
Chaitra 2070	31	69.5	3507	132.4
	32	54.9	4320	119.3
	33	94.5	3926	185.5
	34	75.6	4320	124.6
	35	56.8	4320	121.1
	36	90.4	4320	162.1
	37	114.3	4320	187.3
	38	73.4	4320	132.6
	39	75.2	4451	139.1
	40	76.8	4262	115.8
	41	60.9	4662	120.6
	42	81.2	4130	111.0
	43	54.7	4320	88.4
	44	67.5	3052	111.6
	45	47.7	4320	98.6
	46	49.4	4790	107.4
	47	91.9	3740	163.7
	48	117.1	3878	172.4
	49	201.4	4320	181.8
	50	258.6	4320	153.7
	51	211.7	4320	176.3
	52	148.2	4320	141.8
	53	109.7	3232	138.0
	54	281.9	4219	1982.7
	55	92.6	3783	115.8
	56	27.0	4320	66.7
	57	58.1	4320	100.2
	58	73.1	4309	120.6
	59	72.9	4320	119.8
	60	65.6	4320	127.0
	Total	98.4	125061	392.5

	199	2.7	4320	16.3
	200	13.5	4320	34.1
	201	17.2	2733	38.4
	202	1.0	1482	12.3
	203	8.0	4321	36.3
	204	4.4	4320	20.5
	205	9.7	4320	29.7
	206	9.8	4320	29.7
	207	8.9	4320	28.5
	208	9.9	4320	29.8
	209	25.1	4320	43.4
	210	26.0	4320	44.7
	211	26.2	4320	44.4
	212	22.1	4320	41.6
	213	27.0	4320	44.4
	214	27.9	4502	44.9
	215	35.8	3515	47.9
	216	23.4	3587	42.4
	Total	13.8	126570	35.0
Aswin 2071	217	0.0	4046	0.0
	218	6.2	4319	24.1
	219	19.0	4320	39.2
	220	31.0	4320	46.6
	221	31.2	4320	46.6
	222	32.4	4320	46.9
	223	28.6	4320	45.2
	224	16.3	4320	36.9
	225	9.2	1788	29.0
	226	20.5	3972	40.4
	227	26.1	4320	58.5
	228	54.5	4320	74.9
	229	82.4	4320	88.8
	230	87.6	4320	80.2
	231	13.1	4539	43.4
	232	0.3	4320	6.5
	233	0.9	4320	11.7
	234	0.1	4320	3.2
	235	0.1	4320	4.6
	236	0.0	4320	0.0
	237	0.0	4320	0.0
	238	6.3	4320	30.8
	239	15.5	4320	55.2
	240	81.7	4101	153.0
	241	79.4	4320	84.5
	242	91.9	4320	103.4
	243	244.3	4320	205.1
	244	321.3	4320	193.6
	245	137.6	4320	140.5
	246	116.4	522	137.4

	61	1534.5	2363	2239.3		247	0.0	4320	0.0
	62	1016.8	3229	1943.7		Total	49.0	126967	107.9
	63	215.2	4320	293.8	Kartik 2071	248	38.7	3135	63.2
	64	144.5	4320	220.4		249	23.1	5760	50.8
	65	148.3	4320	229.6		250	27.0	5760	51.4
	66	119.1	4320	192.2		251	67.4	5760	131.9
	67	150.1	4320	224.4		252	190.6	4630	201.0
	68	230.7	4641	680.7		253	43.3	4010	68.5
	69	739.8	3799	2119.6		254	47.4	5760	82.6
	70	149.7	4320	282.6		255	58.3	5760	88.7
	71	318.8	4278	769.4		256	31.4	5760	65.1
	72	733.3	4362	1764.5		257	50.7	5760	99.1
	73	139.8	4320	197.3		258	59.8	5760	107.7
	74	239.2	4320	548.2		259	72.0	5760	114.3
	75	166.6	4320	254.6		260	59.2	5760	109.1
Baishak 2071	76	165.1	4320	259.7		261	54.5	5760	102.8
	77	149.5	4320	251.9		262	115.5	5760	154.6
	78	196.9	4320	261.9		263	205.5	5248	224.6
	79	155.2	4320	166.7		264	51.6	5760	101.3
	80	420.0	4662	1073.3		265	50.6	5760	100.3
	81	3008.1	4320	5397.4		266	53.0	5760	102.9
	82	307.3	4074	612.6		267	53.5	5760	103.9
	83	115.0	4320	167.4		268	49.0	5760	96.6
	84	109.5	4320	127.8		269	55.4	5760	98.1
	85	90.8	4320	102.0		270	53.8	5760	104.4
	86	112.9	4320	139.5		271	57.4	5760	106.3
	87	131.5	4320	156.6		272	61.4	5760	107.4
	88	185.0	4320	211.3		273	62.0	5760	106.8
	89	189.5	4320	358.9		274	75.7	5760	114.9
	90	191.4	4320	253.4		275	101.4	5760	123.7
	91	160.8	4320	191.7		276	120.5	5760	115.6
	Total	354.5	130768	1349.8		277	151.0	5760	120.2
Jestha 2071	92	189.5	3263	220.8		Total	70.9	166783	120.4
	93	203.9	3799	247.9	Manshir 2071	278	180.1	2886	183.8
	94	183.6	4516	249.6		279	190.0	4320	201.7
	95	127.1	1454	194.6		280	208.1	4320	213.7
	96	142.5	4320	222.9		281	69.4	4320	149.8
	97	165.5	4320	238.2		282	114.3	4320	174.3
	98	100.3	4320	147.2		283	181.5	4320	190.0
	99	205.3	4295	241.2		284	230.9	4320	153.9
	100	157.5	4425	224.9		285	247.7	4320	97.9
	101	209.5	5735	277.3		286	201.0	4320	137.2
	102	85.7	2474	143.8		287	247.3	4320	123.8
	103	315.5	4334	284.0		288	259.1	4320	95.7
	104	226.0	4320	198.0		289	273.7	4320	97.2
	105	104.4	4320	142.5		290	279.5	4320	94.2
	106	186.6	6614	257.2		291	259.6	4320	107.3
	107	34.6	1967	146.7		292	214.0	4320	115.9
	108	22.7	4320	57.8		293	241.1	5754	112.5

	109	72.3	4320	101.7
	110	78.0	4320	100.8
	111	106.3	4662	328.8
	112	29.5	4168	72.7
	113	249.7	6558	491.3
	114	6.3	1856	31.9
	115	51.8	4320	81.5
	116	42.1	4320	74.8
	117	135.6	6192	526.0
	118	160.8	4320	183.4
	119	190.3	4320	225.4
	120	214.3	4320	379.9
	121	165.2	4320	214.8
	122	188.4	3676	255.8
	Total	148.5	130468	268.7
Ashad 2071	123	13.4	3330	85.3
	124	30.8	4320	73.0
	125	110.9	3382	528.6
	126	150.8	4641	1211.5
	127	46.4	4320	80.6
	128	57.8	4641	84.0
	129	75.6	4246	86.3
	130	46.5	4188	76.3
	131	86.3	4602	595.7
	132	57.8	5143	304.8
	133	19.0	2734	62.8
	134	27.0	4544	68.6
	135	19.4	4475	54.9
	136	21.1	4335	55.9
	137	60.7	6473	187.9
	138	3.0	2535	23.8
	139	0.3	4386	7.4
	140	0.0	4320	0.0
	141	0.0	4320	0.0
	142	0.1	3934	4.5
	143	0.0	4489	0.0
	144	0.0	4537	0.0
	145	171.6	4680	219.0
	146	269.7	3315	1239.3
	147	35.7	4320	73.1
	148	45.6	4317	83.9
	149	64.9	4323	114.5
	150	199.2	5325	243.8
	151	307.9	4320	280.4
	152	331.9	4320	278.7
	153	957.5	4321	1060.3
	154	433.2	2391	1014.5
	Total	110.8	135527	459.4
Shrawan 2071	155	65.0	4311	88.6
	156	3.8	3552	29.7
	294	216.8	4320	151.5
	295	203.7	4320	170.3
	296	187.8	4320	177.8
	297	69.0	4320	83.3
	298	232.6	4320	159.0
	299	211.3	4320	127.7
	300	174.4	3542	112.1
	301	223.6	5098	122.3
	302	211.6	4320	99.7
	303	211.6	4320	99.7
	304	306.4	4320	106.2
	305	248.7	4320	104.1
	306	227.6	4320	101.5
	Total	212.1	125280	147.3
Poush 2071	307	331.9	2535	139.0
	308	280.3	4320	175.6
	309	273.8	4170	172.8
	310	253.3	4320	179.8
	311	260.4	4320	185.2
	312	253.9	4320	180.7
	313	195.2	4320	203.8
	314	204.0	4320	198.2
	315	229.2	4320	199.9
	316	410.9	4320	118.9
	317	359.5	4320	168.6
	318	379.0	4320	139.9
	319	341.3	4320	207.8
	320	216.8	4320	194.9
	321	207.6	4320	200.3
	322	236.5	3673	203.1
	323	218.6	3983	200.2
	324	160.0	4320	216.5
	325	154.3	4320	217.8
	326	136.2	4320	188.3
	327	126.1	4320	188.5
	328	116.9	4320	172.9
	329	131.4	4320	194.6
	330	145.6	4320	212.9
	331	147.2	4320	218.0
	332	220.9	4320	249.9
	333	237.0	4320	233.8
	334	142.0	4155	218.4
	335	168.6	4485	216.1
	336	151.8	4320	212.4
	Total	221.4	126681	211.4
Magh 2071	337	538.6	3674	261.3
	338	398.0	3015	223.9
	339	489.6	4320	266.5
	340	511.5	4320	270.9
	341	572.2	1953	291.8

	157	1.7	4319	16.1
	158	7.1	4320	34.6
	159	57.1	4320	303.7
	160	91.4	4320	783.0
	161	20.8	4320	53.3
	162	71.7	4320	92.5
	163	48.2	4320	72.6
	164	39.7	4320	68.4
	165	16.3	4320	48.0
	166	49.5	4320	330.1
	167	9.1	4320	36.8
	168	116.9	4320	730.9
	169	4.2	4320	25.4
	170	7.0	4318	32.5
	171	2.9	5509	21.1
	172	21.8	1879	54.4
	173	3.0	2660	21.6
	174	2.5	4320	19.8
	175	3.1	4320	21.8
	176	11.2	4320	40.5
	177	33.2	4320	65.2
	178	30.2	4320	62.5
	179	12.1	4320	42.0
	180	3.1	4320	22.0
	181	6.9	4320	32.2
	182	25.3	4320	58.3
	183	88.6	4320	80.1
	184	83.3	4320	89.1
	185	42.1	4320	69.7
	Total	32.0	130228	219.6

	342	203.9	3669	128.2
	343	382.6	3018	193.1
	344	470.2	4320	261.8
	345	414.6	4320	233.4
	346	422.7	4320	259.1
	347	458.0	4320	271.0
	348	497.2	4320	266.2
	349	489.0	4320	257.0
	350	498.1	4320	273.2
	351	548.9	1953	304.5
	352	331.0	4320	186.4
	353	322.8	4320	184.4
	354	310.6	4320	183.0
	355	624.1	4320	234.3
	356	614.6	4320	239.5
	357	603.8	4320	225.4
	358	624.3	4320	232.1
	359	639.1	4320	248.1
	360	635.8	4320	233.5
	361	792.3	4320	442.7
	362	712.0	4320	421.5
	363	756.5	4320	255.8
	364	715.5	4320	240.6
	365	587.3	4320	220.3
	Total	526.1	116642	294.8

Table A12: $PM_{2.5}$ assessment of hourly intervals for all stations

Hourly Interval	Mean	N	SD	CV
0-1 AM	37.4	3594	34.9	93.4
1-2 AM	35.9	3589	32.6	90.8
2-3 AM	35.4	3587	31.3	88.6
3-4 AM	36.2	3586	32.4	89.6
4-5 AM	39.6	3583	33.5	84.4
5-6 AM	46.5	3577	39.4	84.9
6-7 AM	58.5	3577	47.2	80.7
7-8 AM	77.0	3570	64.8	84.2
8-9 AM	86.6	3569	72.3	83.5
9-10 AM	82.3	3582	80.1	97.4
10-11 AM	66.1	3573	63.6	96.3
11-12 NOON	50.4	3581	49.3	97.8
12-1 PM	39.7	3571	42.2	106.2
1-2 PM	33.3	3588	37.4	112.4
2-3 PM	31.2	3571	35.7	114.4
3-4 PM	32.8	3569	50.2	152.7
4-5 PM	35.2	3560	39.0	110.8
5-6 PM	41.4	3565	38.1	92.1
6-7 PM	49.8	3580	44.9	90.1
7-8 PM	57.7	3583	52.6	91.2
8-9 PM	59.4	3574	62.6	105.3
9-10 PM	54.9	3582	60.5	110.0
10-11 PM	47.8	3591	50.9	106.6
11-12 MIDNIGHT	43.8	3592	52.8	120.6
Total	49.1	85894	52.1	106.0

Table A13: $PM_{2.5}$ assessment of hourly intervals between stations

Hour	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
0-1 AM	50.1	724	38.4	33.8	1452	29.8	34.5	1418	36.4
1-2 AM	46.8	724	35.6	31.7	1450	28.2	34.7	1415	34.0
2-3 AM	45.4	724	34.5	31.3	1450	27.9	34.4	1413	31.9
3-4 AM	44.8	724	34.5	31.5	1448	29.8	36.5	1414	32.9
4-5 AM	46.7	724	35.4	34.8	1445	31.0	40.9	1414	34.1
5-6 AM	53.0	724	38.4	38.8	1440	34.7	51.0	1413	43.0
6-7 AM	66.6	724	45.4	49.6	1439	43.1	63.5	1414	50.6
7-8 AM	83.9	724	55.5	67.7	1431	58.4	82.8	1415	73.8
8-9 AM	98.4	724	63.8	79.1	1431	72.9	88.0	1414	74.9
9-10 AM	96.3	724	64.6	73.2	1444	89.0	84.4	1414	76.5
10-11 AM	82.8	724	56.3	53.4	1435	60.5	70.2	1414	67.6
11-12 NOON	64.9	725	46.9	38.7	1443	42.0	54.8	1413	54.5
12-1 PM	50.3	724	34.7	31.7	1431	44.6	42.4	1416	41.7
1-2 PM	41.6	726	28.8	28.3	1444	45.7	34.1	1418	30.4
2-3 PM	39.2	726	25.7	25.5	1430	38.5	32.8	1415	36.2
3-4 PM	39.9	725	27.0	26.6	1428	44.2	35.6	1416	62.6
4-5 PM	42.8	726	28.3	27.8	1416	37.9	38.7	1418	43.4
5-6 PM	47.9	726	34.7	34.7	1421	35.8	44.9	1418	41.0
6-7 PM	56.7	726	42.5	43.0	1436	43.5	53.3	1418	46.5
7-8 PM	66.6	726	47.1	54.6	1436	57.7	56.3	1421	49.4
8-9 PM	69.6	726	51.1	61.3	1426	76.5	52.4	1422	50.4
9-10 PM	66.6	724	52.9	57.6	1438	73.1	46.3	1420	47.2
10-11 PM	60.3	724	47.8	49.1	1447	60.7	40.0	1420	38.6
11-12 MIDNIGHT	54.3	723	43.9	45.0	1449	66.7	37.1	1420	37.7
Total	59.0	17391	46.7	43.7	34510	53.9	49.6	33993	52.0

Table A14: CO assessment of hourly intervals for all stations

Hourly Interval	Mean	N	SD	CV
0-1 AM	181.3	61299	680.9	375.5
1-2 AM	167.6	60874	671.7	400.8
2-3 AM	153.3	61126	612.9	399.9
3-4 AM	136.2	60931	609.0	447.1
4-5 AM	118.3	60741	460.6	389.2
5-6 AM	205.5	61132	670.7	326.4
6-7 AM	454.1	60940	1053.3	231.9
7-8 AM	552.6	60744	1078.7	195.2
8-9 AM	545.4	61154	1041.1	190.9

9-10 AM	620.0	60916	1322.9	213.4
10-11 AM	634.9	60704	1868.0	294.2
11-12 NOON	513.7	61196	2144.5	417.5
12-1 PM	674.9	61004	6747.2	999.8
1-2 PM	680.2	60834	5826.1	856.5
2-3 PM	665.1	61194	6941.9	1043.8
3-4 PM	475.9	61134	3428.6	720.4
4-5 PM	399.7	61228	1802.5	451.0
5-6 PM	424.2	61694	1293.4	304.9
6-7 PM	624.6	61513	1371.4	219.6
7-8 PM	726.2	61302	1307.0	180.0
8-9 PM	592.7	61706	1113.0	187.8
9-10 PM	493.7	61496	1215.3	246.2
10-11 PM	298.1	61318	893.9	299.9
11-12 MIDNIGHT	188.9	61554	602.1	318.7
Total	438.7	1467734	2646.0	603.2

Table A15: CO between-stations hourly levels

Hour	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
0-1 AM	361.6	21924	910.2	66.9	22489	516.0	99.8	16886	432.2
1-2 AM	345.3	21746	910.7	58.7	22353	493.8	82.4	16775	416.2
2-3 AM	325.6	21845	828.5	56.0	22447	467.7	59.3	16834	348.9
3-4 AM	285.8	21777	850.1	56.6	22379	441.3	48.1	16775	322.3
4-5 AM	240.3	21707	579.9	42.4	22313	329.4	61.4	16721	399.0
5-6 AM	429.4	21854	856.6	74.6	22447	488.1	89.3	16831	511.5
6-7 AM	1023.7	21778	1289.9	114.2	22379	647.7	168.4	16783	808.0
7-8 AM	1137.1	21700	1248.9	161.9	22312	658.5	315.7	16732	959.3
8-9 AM	1043.9	21858	1280.6	182.3	22450	654.4	382.7	16846	843.5
9-10 AM	1141.8	21739	1741.9	203.1	22383	628.0	500.0	16794	1138.4
10-11 AM	1029.0	21629	1843.7	379.4	22297	1847.8	466.5	16778	1841.3
11-12 NOON	857.5	21759	1916.1	378.1	22481	2749.6	252.3	16956	1272.4
12-1 PM	1251.7	21647	9548.4	460.9	22426	5810.4	220.8	16931	1434.8
1-2 PM	1417.3	21585	8898.8	297.8	22372	3698.2	244.4	16877	1366.7
2-3 PM	1536.3	21731	11474.4	181.0	22503	1419.2	191.0	16960	999.0
3-4 PM	1013.3	21731	5576.0	169.6	22466	901.4	192.8	16937	941.7
4-5 PM	810.4	21793	2766.4	147.7	22471	805.7	205.8	16964	835.0
5-6 PM	845.6	21971	1819.2	132.7	22630	723.5	268.5	17093	852.0
6-7 PM	1206.5	21903	1777.5	191.8	22559	787.2	449.9	17051	1092.6
7-8 PM	1372.6	21821	1513.0	281.9	22488	957.8	484.1	16993	1073.6
8-9 PM	1192.2	21974	1352.0	183.6	22626	657.6	363.9	17106	901.8
9-10 PM	1014.0	21895	1678.7	156.5	22554	644.3	271.5	17047	782.2

10-11 PM	601.2	21833	1160.0	95.3	22492	585.8	177.2	16993	716.4
1 1 - 1 2 MIDNIGHT	391.3	21898	846.1	48.7	22581	286.1	114.8	17075	443.4
Total	869.2	523098	3964.3	171.7	538898	1687.8	238.2	405738	952.5

Table A16 : NO_2 hourly levels for all stations

Hour	Mean	N	SD	CV
0-1 AM	163.5	65359	301.9	184.7
1-2 AM	166.5	58852	274.3	164.8
2-3 AM	170.9	56144	278.1	162.7
3-4 AM	163.0	55196	236.4	145.1
4-5 AM	159.5	46951	228.2	143.1
5-6 AM	180.7	46731	245.0	135.6
6-7 AM	237.6	46636	421.2	177.3
7-8 AM	255.8	46465	489.9	191.5
8-9 AM	248.8	47537	536.5	215.6
9-10 AM	270.3	47901	1228.1	454.4
10-11 AM	225.4	52678	1105.1	490.4
11-12 NOON	179.4	58879	563.4	314.0
12-1 PM	183.2	61125	781.5	426.6
1-2 PM	175.4	67978	936.9	534.1
2-3 PM	162.3	71298	697.7	429.9
3-4 PM	166.1	72359	936.4	563.8
4-5 PM	142.4	81233	597.5	419.7
5-6 PM	140.4	81699	403.3	287.3
6-7 PM	178.1	81600	653.2	366.8
7-8 PM	183.9	81302	437.1	237.7
8-9 PM	179.8	80320	341.6	190.1
9-10 PM	159.6	79649	300.6	188.4
10-11 PM	147.3	74343	254.3	172.7
11-12 MIDNIGHT	149.3	68416	266.7	178.7
Total	178.2	1530651	586.8	329.4

Table A17: NO_2 between-stations hourly levels

Hour	Kathmandu			Bhaktapur			Lalitpur		
	Mean	N	SD	Mean	N	SD	Mean	N	SD
0-1 AM	179.1	21444	217.2	190.3	20072	399.9	126.8	23843	265.9
1-2 AM	188.6	19393	209.5	191.2	17663	362.8	126.7	21796	234.2
2-3 AM	198.9	18365	226.7	191.8	17018	378.0	129.0	20761	209.0
3-4 AM	194.5	18215	204.9	171.6	16371	306.6	128.2	20610	189.0
4-5 AM	186.1	15868	190.6	169.7	12932	296.6	129.0	18151	196.7

5-6 AM	206.5	15800	196.8	186.9	12854	306.8	153.8	18077	230.4
6-7 AM	250.2	15765	273.0	235.4	12826	448.2	228.1	18045	500.5
7-8 AM	266.0	15640	322.6	249.0	12900	516.6	251.7	17925	582.2
8-9 AM	259.4	15758	359.5	240.0	13748	571.4	246.3	18031	630.0
9-10 AM	268.7	15699	782.2	267.0	14224	1420.9	274.3	17978	1373.7
10-11 AM	227.1	16538	714.8	226.7	17152	1270.6	222.6	18988	1218.5
11-12 NOON	187.5	18037	399.0	170.2	20349	574.1	181.6	20493	666.8
12-1 PM	186.7	18561	704.7	167.3	21528	741.8	196.4	21036	879.1
1-2 PM	187.0	20685	898.5	152.0	24022	884.7	189.3	23271	1018.8
2-3 PM	160.1	21712	466.2	150.4	24974	716.1	176.3	24612	835.2
3-4 PM	162.7	21745	597.2	150.0	25832	972.5	185.8	24782	1122.9
4-5 PM	161.8	24334	384.1	123.0	29558	572.7	146.0	27341	757.8
5-6 PM	171.5	24449	300.2	117.5	29685	358.3	137.5	27565	512.3
6-7 PM	212.4	24420	503.3	152.6	29640	667.5	175.1	27540	747.2
7-8 PM	213.2	24389	320.4	158.8	29400	427.5	184.8	27513	526.3
8-9 PM	204.5	24330	249.3	159.2	28546	329.1	179.2	27444	415.8
9-10 PM	186.9	24298	225.1	146.3	27932	306.3	148.9	27419	347.9
10-11 PM	176.7	23338	204.0	142.3	24726	279.1	125.8	26279	267.2
11-12 MIDNIGHT	176.1	21899	214.3	162.5	21738	338.2	114.0	24779	231.0
Total	197.3	480682	429.2	168.9	505690	622.9	169.9	544279	667.0

Table A18: Between-station CO variation

Interval	Kathmandu				Bhaktapur			Lalitpur			
	Mean	N	SD	Ratio	Mean	N	SD	Mean	N	SD	Ratio
1-8 HOUR (MIDNIGHT-MORNING)	518.2	174331	1014.0	6.57	78.9	179119	516.5	115.46	134337	573.6	1.46
9-16 HOUR (MORNING-AFTERNOON)	1161.0	173679	6563.7	4.13	281.4	179378	2786.8	305.9	135079	1271.1	1.09
17-24 HOUR (AFTERNOON-MIDNIGHT)	929.3	175088	1727.2	6.01	154.7	180401	708.3	2912	136322	867.7	1.89
Total	869.2	523098	3964.3	5.06	171.7	538898	1687.8	238.2	405738	952.5	1.39

Table A19: Station-wise comparisons of $PM_{2.5}$ with load shedding at station 1

Three hourly interval		Mean	N	SD	CV
AFTER MIDNIGHT (0-3 AM)	Normal Time	34.2	4174	34.0	99.6
	Load Shedding Time	55.1	72	33.7	61.2
BEFORE DAWN (3-6 AM)	Normal Time	39.4	3623	36.0	91.5
	Load Shedding Time	62.8	618	39.4	62.7
MORNING (6-9 AM)	Normal Time	70.8	2114	64.1	90.5
	Load Shedding Time	85.3	2129	71.2	83.5
BEFORE NOON (9-12 NOON)	Normal Time	58.7	1598	62.2	105.9
	Load Shedding Time	76.5	2643	70.3	91.8
AFTERNOON (12-3 PM)	Normal Time	34.0	1781	38.6	113.4
	Load Shedding Time	38.1	2468	35.1	91.9
LATE AFTERNOON (3-6 PM)	Normal Time	34.8	2049	26.0	74.7
	Load Shedding Time	44.3	2203	64.6	145.7
EVENING (6-9 PM)	Normal Time	51.4	1748	46.5	90.5
	Load Shedding Time	55.8	2513	50.3	90.2
NIGHT (9-12 MIDNIGHT)	Normal Time	39.1	3053	43.5	111.2
	Load Shedding Time	46.4	1207	35.8	77.1

Table A20: Station-wise comparisons of $PM_{2.5}$ with load shedding at station 2

Three hourly interval		Mean	N	SD	CV
AFTER MIDNIGHT (0-3 AM)	Normal Time	32.1	4280	28.8	89.7
	Load Shedding Time	42.5	72	18.5	43.6
BEFORE DAWN (3-6 AM)	Normal Time	33.1	3682	31.1	94.0
	Load Shedding Time	46.1	651	35.1	76.1
MORNING (6-9 AM)	Normal Time	54.3	1997	55.5	102.2
	Load Shedding Time	75.1	2304	63.1	84.1
BEFORE NOON (9-12 NOON)	Normal Time	49.8	1619	78.6	157.8
	Load Shedding Time	58.3	2703	60.9	104.4
	Total	55.1	4322	68.2	123.7
AFTERNOON (12-3 PM)	Normal Time	25.3	1847	35.0	138.5
	Load Shedding Time	30.9	2458	48.2	155.8
	Total	28.5	4305	43.1	151.2
LATE AFTERNOON (3-6 PM)	Normal Time	28.1	2075	36.7	130.7
	Load Shedding Time	31.2	2190	42.2	135.2

EVENING (6-9 PM)	Normal Time	50.1	1780	60.9	121.4
	Load Shedding Time	54.9	2518	61.3	111.7
NIGHT (9-12 MIDNIGHT)	Normal Time	46.3	3117	64.3	139.0
	Load Shedding Time	61.6	1217	73.1	118.8

Table A21: Station-wise comparisons of PM2.5 with load shedding at station 3

Three hourly interval		Mean	N	SD	CV
AFTER MIDNIGHT (0-3 AM)	Normal Time	34.2	4174	34.0	99.6
	Load Shedding Time	55.1	72	33.7	61.2
BEFORE DAWN (3-6 AM)	Normal Time	39.4	3623	36.0	91.5
	Load Shedding Time	62.8	618	39.4	62.7
MORNING (6-9 AM)	Normal Time	70.8	2114	64.1	90.5
	Load Shedding Time	85.3	2129	71.2	83.5
BEFORE NOON (9-12 NOON)	Normal Time	58.7	1598	62.2	105.9
	Load Shedding Time	76.5	2643	70.3	91.8
AFTERNOON (12-3 PM)	Normal Time	34.0	1781	38.6	113.4
	Load Shedding Time	38.1	2468	35.1	91.9
LATE AFTERNOON (3-6 PM)	Normal Time	34.8	2049	26.0	74.7
	Load Shedding Time	44.3	2203	64.6	145.7
EVENING (6-9 PM)	Normal Time	51.4	1748	46.5	90.5
	Load Shedding Time	55.8	2513	50.3	90.2
NIGHT (9-12 MIDNIGHT)	Normal Time	39.1	3053	43.5	111.2
	Load Shedding Time	46.4	1207	35.8	77.1

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