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

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Nepal Health Research Council
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
da 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
NO₂  Nitrogen Dioxide
PM   Particulate Matter / Afternoon/Post Meridiem
PM₅.₅ Particulate Matter with Aerodynamic Size less than 2.5 Microns
q-q Quantile - Quantile
RH   Relative Humidity
RC   Recoded
RR   Relative Risk
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sig</td>
<td>Significant</td>
</tr>
<tr>
<td>Std</td>
<td>Standard</td>
</tr>
<tr>
<td>TUTH</td>
<td>Tribhuvan University Teaching Hospital</td>
</tr>
<tr>
<td>UARI</td>
<td>Upper Acute Respiratory Infection</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>µg</td>
<td>Microgram</td>
</tr>
<tr>
<td>VIF</td>
<td>Variance Inflation Factor</td>
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<tr>
<td>Z</td>
<td>Standardized value</td>
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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/m³. Moreover, concentrations of NO$_2$ in ambient air are also found to be high, with several very high spikes monitored above 1000 µg/m³, which is around 12 times higher than 24-hour national standard of 80µg/m³. 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/m³) during post-midnight and before dawn (12-5 AM). The level gradually increases throughout the morning and peaks at 87 µg/m³ during 8-9 AM. Then gradually decreases and reaches lowest value (31 µg/m³) during the afternoon (2-3 PM). Thereafter, the level gradually increases again and reaches maximum (59 µg/m³) 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/m³), which start to increase during early morning (5-6 AM) and reach around 635 µg/m³ during 10-11 AM. The level remains relatively high during the day until 2-3 PM (500-670 µg/m³) then decrease to 400 µg/m³ around 4-5 PM. The level again increases to around 725 during 7-8 PM and decrease thereafter from midnight (189 µg/m³) to the dawn (118 µg/m³). Nonetheless, the values are well below the 8 hour NAAQS of 10000 µg/m³.

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/m³. Relatively, the levels are on the lower side after midnight and before dawn (160-170 µg/m³) and start rising in the early morning.
The level rise to around 270 µg/m³ during 9-10 AM and start to decrease gradually during day time, reaching 140 µg/m³ during 4-6 PM, which then rises to around 180 µg/m³ during 6-9 PM and then starts to decrease until midnight (150 µg/m³).

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/m³ 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$^\circ$ 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 µg/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 µg/m$^3$ rise in CO level (same day effect), temperature is associated with a 1.4% rise in mortality per 1ºCelsius 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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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 NO₂ 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).
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
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>
<thead>
<tr>
<th>Measurement</th>
<th>Pollutant</th>
<th>Pollution measurements</th>
<th>Compiling hospital data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td>PM$_{2.5}$</td>
<td>3 clusters * 24 hours * 12 months of daily monitoring (around 365 days)</td>
<td>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>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>CO</td>
<td>3 clusters * 24 hours * 12 months of daily monitoring (around 365 days)</td>
<td></td>
</tr>
</tbody>
</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/m$^3$. 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\textsubscript{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\textsubscript{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.

\[
\log_e(\mu) = \beta_0 + \sum \beta_i x_i
\]

where \( \mu \) 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 $\beta$ 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.

$$RR_k = e^{\hat{\beta}_k(C_k - T_k)}$$  \hspace{1cm} (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.

$$AF = \frac{\sum P_iRR_i}{\sum P_i} \times 1$$  \hspace{1cm} (3)

Where

$P_i = $ the proportion of the population at exposure category ‘$i$’, including the unexposed (i.e. $\sum P_i$ becomes $(P_{1}RR_{1} + P_{2}RR_{2} + \ldots + P_{\text{unexposed}} \times 1)$).

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.

$$EBD = AF \times \text{Total Burden}$$  \hspace{1cm} (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

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Measured unit</th>
<th>Converted unit</th>
<th>Conversion factor</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>µg/m$^3$</td>
<td>No change</td>
<td>Not required</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>ppm</td>
<td>µg/m$^3$</td>
<td>1ppm = 1145 µg/m$^3$</td>
<td>-</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>mg/m$^3$</td>
<td>µg/m$^3$</td>
<td>1 mg/m$^3$ = 1000 µg/m$^3$</td>
<td>-</td>
</tr>
<tr>
<td>(Station 2 &amp; 3)</td>
<td>ppm</td>
<td>µg/m$^3$</td>
<td>1 ppm = 1880 µg/m$^3$</td>
<td>at 250°C and 1 atmosphere pressure</td>
</tr>
</tbody>
</table>


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

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Unit</th>
<th>Averaging Time</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>µg/m$^3$</td>
<td>24 hour</td>
<td>40</td>
</tr>
<tr>
<td>CO</td>
<td>µg/m$^3$</td>
<td>8 hour</td>
<td>10000</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>µg/m$^3$</td>
<td>24 hour</td>
<td>80</td>
</tr>
</tbody>
</table>

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.
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 µg/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

<table>
<thead>
<tr>
<th>Season</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring/Pre-monsoon</td>
<td>Falgun-Baishak</td>
</tr>
<tr>
<td>Summer/Monsoon</td>
<td>Jestha-Shrawan</td>
</tr>
<tr>
<td>Autumn/Post-monsoon</td>
<td>Bhadra-Kartik</td>
</tr>
<tr>
<td>Winter</td>
<td>Manshir-Magh</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Season</th>
<th>Mean</th>
<th>N</th>
<th>SD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>447.3</td>
<td>348518</td>
<td>1541.90</td>
<td>344.7</td>
</tr>
<tr>
<td>Summer</td>
<td>502.7</td>
<td>345159</td>
<td>4937.17</td>
<td>982.1</td>
</tr>
<tr>
<td>Autumn</td>
<td>298.4</td>
<td>397446</td>
<td>1180.25</td>
<td>395.5</td>
</tr>
<tr>
<td>Winter</td>
<td>517.3</td>
<td>380150</td>
<td>1116.11</td>
<td>215.8</td>
</tr>
<tr>
<td>Total</td>
<td>438.2</td>
<td>1471273</td>
<td>2643.43</td>
<td>603.3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Season</th>
<th>Mean</th>
<th>N</th>
<th>SD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>267.0</td>
<td>374746</td>
<td>1075.1</td>
<td>402.6</td>
</tr>
<tr>
<td>Summer</td>
<td>97.3</td>
<td>396223</td>
<td>337.9</td>
<td>347.2</td>
</tr>
<tr>
<td>Autumn</td>
<td>47.1</td>
<td>420320</td>
<td>101.0</td>
<td>214.3</td>
</tr>
<tr>
<td>Winter</td>
<td>314.7</td>
<td>368603</td>
<td>266.3</td>
<td>84.6</td>
</tr>
<tr>
<td>Total</td>
<td>175.9</td>
<td>1559892</td>
<td>582.0</td>
<td>330.9</td>
</tr>
</tbody>
</table>

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).
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

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

<table>
<thead>
<tr>
<th></th>
<th>PM$_{2.5}$</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>-.863**</td>
<td>-.404</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.192</td>
<td>.008</td>
</tr>
<tr>
<td>Temperature</td>
<td>Pearson Correlation</td>
<td>-.863**</td>
<td>1</td>
<td>.009</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.977</td>
<td>.100</td>
</tr>
<tr>
<td>Humidity</td>
<td>Pearson Correlation</td>
<td>-.404</td>
<td>.009</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.192</td>
<td>.977</td>
<td>.088</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Pearson Correlation</td>
<td>-.724**</td>
<td>.498</td>
<td>.513</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.008</td>
<td>.100</td>
<td>.088</td>
</tr>
</tbody>
</table>

** 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

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Correlation</td>
<td>1</td>
<td>-.197</td>
<td>.053</td>
<td>-.282</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.539</td>
<td>.870</td>
<td>.375</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>-.197</td>
<td>1</td>
<td>.009</td>
<td>.498</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.539</td>
<td>.977</td>
<td>.100</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>.053</td>
<td>.009</td>
<td>1</td>
<td>.513</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.870</td>
<td>.977</td>
<td>.088</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>-.282</td>
<td>.498</td>
<td>.513</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.375</td>
<td>.100</td>
<td>.088</td>
<td></td>
</tr>
</tbody>
</table>

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 \( \text{PM}_{2.5} \). 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

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean</th>
<th>N</th>
<th>SD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falgun 2070</td>
<td>348.2</td>
<td>118917</td>
<td>1196.7</td>
<td>343.7</td>
</tr>
<tr>
<td>Chaitra 2070</td>
<td>98.4</td>
<td>125061</td>
<td>392.5</td>
<td>398.9</td>
</tr>
<tr>
<td>Baishak 2071</td>
<td>354.5</td>
<td>130768</td>
<td>1349.8</td>
<td>380.8</td>
</tr>
<tr>
<td>Jestha 2071</td>
<td>148.5</td>
<td>130468</td>
<td>268.7</td>
<td>181.0</td>
</tr>
<tr>
<td>Ashad 2071</td>
<td>110.8</td>
<td>135527</td>
<td>459.4</td>
<td>414.7</td>
</tr>
<tr>
<td>Shrawan 2071</td>
<td>32.0</td>
<td>130228</td>
<td>219.6</td>
<td>685.9</td>
</tr>
<tr>
<td>Bhadra 2071</td>
<td>13.8</td>
<td>126570</td>
<td>35.0</td>
<td>253.4</td>
</tr>
<tr>
<td>Aswin 2071</td>
<td>49.0</td>
<td>126967</td>
<td>107.9</td>
<td>220.2</td>
</tr>
<tr>
<td>Kartik 2071</td>
<td>71.0</td>
<td>166783</td>
<td>120.4</td>
<td>169.6</td>
</tr>
<tr>
<td>Manshir 2071</td>
<td>212.1</td>
<td>125280</td>
<td>147.3</td>
<td>69.4</td>
</tr>
<tr>
<td>Poush 2071</td>
<td>221.4</td>
<td>126681</td>
<td>211.4</td>
<td>95.5</td>
</tr>
<tr>
<td>Magh 2071</td>
<td>526.1</td>
<td>116642</td>
<td>294.8</td>
<td>56.0</td>
</tr>
<tr>
<td>Total</td>
<td>175.9</td>
<td>155982</td>
<td>582.0</td>
<td>330.9</td>
</tr>
</tbody>
</table>

**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.
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

Figure 6: Weather and NO₂ scenario of Kathmandu valley (for all three stations): Assessment of monthly variation

Table 11: Statistical correlation of NO₂ with weather situation

<table>
<thead>
<tr>
<th></th>
<th>NO₂</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>Correlation: 1</td>
<td>-.634*</td>
<td>-.388</td>
<td>-.633*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed): .027</td>
<td>.212</td>
<td>.027</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Correlation: -.634*</td>
<td>1</td>
<td>.009</td>
<td>.498</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed): .027</td>
<td>.977</td>
<td>.100</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>Correlation: -.388</td>
<td>.009</td>
<td>1</td>
<td>.513</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed): .212</td>
<td>.977</td>
<td>.088</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>Correlation: -.633*</td>
<td>.498</td>
<td>.513</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed): .027</td>
<td>.100</td>
<td>.088</td>
<td></td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).

Interpretation /Assessment
High temperature, humidity and rainfall are correlated with low NO₂ levels as seen in the graph above. The negative association between NO₂ 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

![Graph showing PM2.5 levels across months for Kathmandu, Bhaktapur, and Lalitpur stations.](image)

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).
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\textsubscript{2} scenario of Kathmandu valley (for all three stations): Between stations monthly variation

Interpretation / Assessment
In contrast to CO levels, NO\textsubscript{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\textsubscript{2} may not be largely mediated by traffic only. Low levels of NO\textsubscript{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

![PM$_{2.5}$ scenario of Kathmandu valley (for all the three stations): Assessment of daily variation](image)

**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

<table>
<thead>
<tr>
<th>Correlations with daily averages (N=365)</th>
<th>PM$_{2.5}$</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>Correlation</td>
<td>1</td>
<td>-.711**</td>
<td>-.207**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Temperature</td>
<td>Correlation</td>
<td>-.711**</td>
<td>1</td>
<td>-.091</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.082</td>
<td>.000</td>
</tr>
<tr>
<td>Humidity</td>
<td>Correlation</td>
<td>-.207**</td>
<td>-.091</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.082</td>
<td>.000</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Correlation</td>
<td>-.345**</td>
<td>.250**</td>
<td>.209**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
</tbody>
</table>

**. 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**

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation (N=365)</td>
<td>1</td>
<td>-.069</td>
<td>.063</td>
<td>-.081</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.190</td>
<td>.231</td>
<td>.124</td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>-.069</td>
<td>1</td>
<td>-.091</td>
<td>.250**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.190</td>
<td>.082</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>.063</td>
<td>-.091</td>
<td>1</td>
<td>.209**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.231</td>
<td>.082</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>-.081</td>
<td>.250**</td>
<td>.209**</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.124</td>
<td>.000</td>
<td>.000</td>
<td></td>
</tr>
</tbody>
</table>

**. 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: NO₂ scenario of Kathmandu valley (for all the three stations): Assessment of daily variation**
Interpretation / Assessment

Unusually high spikes of daily NO₂ 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 NO₂, with occasional very high spikes (more than 1000 - more than 12 times higher than the standard). The main sources of NO₂ are vehicular and industrial emissions. The current scenario poses serious health concerns for people living in the valley.

Table 14: Statistical correlation of NO₂ with weather situation (for all the three stations):
Assessment of daily variation

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Humidity</th>
<th>Rainfall</th>
<th>NO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Correlation</td>
<td>.091</td>
<td>.250**</td>
<td>-.350**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.082</td>
<td>.000</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>-.091</td>
<td>1</td>
<td>.209**</td>
<td>-.072</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.082</td>
<td>.000</td>
<td>.169</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>.250**</td>
<td>.209**</td>
<td>1</td>
<td>-.117*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.025</td>
<td></td>
</tr>
<tr>
<td>NO₂</td>
<td>-.350**</td>
<td>-.072</td>
<td>-.117*</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.169</td>
<td>.025</td>
<td></td>
</tr>
</tbody>
</table>

** 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 NO₂ 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

<table>
<thead>
<tr>
<th>Month</th>
<th>Number Outside NAAQS</th>
<th>Number Within NAAQS</th>
<th>Standard</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falgun 2070</td>
<td>28</td>
<td>2</td>
<td>93.3%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Chaitra 2070</td>
<td>29</td>
<td>1</td>
<td>96.7%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Baishak 2071</td>
<td>31</td>
<td>0</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Jestha 2071</td>
<td>14</td>
<td>17</td>
<td>45.2%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Ashad 2071</td>
<td>0</td>
<td>32</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Shrawan 2071</td>
<td>0</td>
<td>31</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Bhadra 2071</td>
<td>0</td>
<td>31</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Aswin 2071</td>
<td>0</td>
<td>31</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Kartik 2071</td>
<td>18</td>
<td>12</td>
<td>60.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Manshir 2071</td>
<td>29</td>
<td>0</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Poush 2071</td>
<td>29</td>
<td>1</td>
<td>96.7%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Magh 2071</td>
<td>29</td>
<td>0</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td>207</td>
<td>158</td>
<td>56.7%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

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

![Graph showing daily midnight-morning averages of CO](image1)

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

The averages are well below the NAAQS (10000 µg/m³) standard.

![Graph showing daily morning-afternoon averages of CO](image2)

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/m³) standard.
### Table 16: NO$_2$ scenario of Kathmandu Valley (for all the three stations): Assessment of 24-hour average

<table>
<thead>
<tr>
<th>Month</th>
<th>Number</th>
<th>Within standard</th>
<th>Above standard</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falgun 2070</td>
<td>5</td>
<td>25</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Chaitra 2070</td>
<td>17</td>
<td>13</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Baishak 2071</td>
<td>0</td>
<td>31</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Jestha 2071</td>
<td>8</td>
<td>23</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Ashad 2071</td>
<td>22</td>
<td>10</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Shrawan 2071</td>
<td>27</td>
<td>4</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Bhadra 2071</td>
<td>31</td>
<td>0</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Aswin 2071</td>
<td>23</td>
<td>8</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>Kartik 2071</td>
<td>24</td>
<td>6</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Manshir 2071</td>
<td>2</td>
<td>27</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Poush 2071</td>
<td>0</td>
<td>30</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Magh 2071</td>
<td>0</td>
<td>29</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td>206</td>
<td></td>
<td>365</td>
</tr>
</tbody>
</table>

#### 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$_2$. 

Note: NAAQS 24-hour average is 80µg/m
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.

![Graph showing CO levels for Kathmandu, Bhaktapur, and Lalitpur](image)

**Figure 18: NO₂ 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\textsubscript{2.5} assessment in 3 hours intervals for all stations

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

Interpretation / Assessment

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

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

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

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

**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

![Graph showing PM2.5 assessment of 3 hour intervals between stations.](image)

**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).
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.
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

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: NO₂ 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

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

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](image)
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
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

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

Figure 33: Station-wise comparison of PM$_{1.5}$ 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>
<thead>
<tr>
<th>Hospital</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bir Hospital</td>
<td>971</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Kanti children’s Hospital</td>
<td>817</td>
<td>7.2</td>
<td>15.8</td>
</tr>
<tr>
<td>TU Teaching Hospital</td>
<td>1842</td>
<td>16.3</td>
<td>32.1</td>
</tr>
<tr>
<td>B&amp;B Hospital</td>
<td>554</td>
<td>4.9</td>
<td>37.0</td>
</tr>
<tr>
<td>Kathmandu Medical College (KMC) Teaching Hospital</td>
<td>977</td>
<td>8.6</td>
<td>45.6</td>
</tr>
<tr>
<td>Kathmandu Model Hospital</td>
<td>799</td>
<td>7.1</td>
<td>52.6</td>
</tr>
<tr>
<td>Ishan Hospital</td>
<td>372</td>
<td>3.3</td>
<td>55.9</td>
</tr>
<tr>
<td>Bhaktapur Hospital</td>
<td>217</td>
<td>1.9</td>
<td>57.8</td>
</tr>
<tr>
<td>OM Hospital</td>
<td>1582</td>
<td>14.0</td>
<td>71.8</td>
</tr>
<tr>
<td>Nepal Medical College (NMC) Teaching Hospital</td>
<td>927</td>
<td>8.2</td>
<td>80.0</td>
</tr>
<tr>
<td>Civil Hospital</td>
<td>103</td>
<td>0.9</td>
<td>80.9</td>
</tr>
<tr>
<td>Patan Hospital</td>
<td>1701</td>
<td>15.0</td>
<td>95.9</td>
</tr>
<tr>
<td>Siddhi Memorial Hospital</td>
<td>459</td>
<td>4.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>11321</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

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

**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>
<thead>
<tr>
<th>Age Group</th>
<th>SEX</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>0-9</td>
<td>1003 8.9%</td>
<td>1863 16.6%</td>
</tr>
<tr>
<td>10-19</td>
<td>233 2.1%</td>
<td>342 3.0%</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Morbidity</th>
<th>Mean Age</th>
<th>N</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPD</td>
<td>65.6</td>
<td>4388</td>
<td>15.5</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>39.7</td>
<td>3286</td>
<td>29.6</td>
<td></td>
<td>99</td>
</tr>
<tr>
<td>Asthma</td>
<td>38.7</td>
<td>547</td>
<td>26.8</td>
<td></td>
<td>99</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>37.9</td>
<td>539</td>
<td>31.5</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>ARI</td>
<td>7.4</td>
<td>1727</td>
<td>15.5</td>
<td></td>
<td>99</td>
</tr>
<tr>
<td>Respiratory Symptom</td>
<td>5.2</td>
<td>92</td>
<td>14.5</td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>Otitis Media</td>
<td>25.3</td>
<td>202</td>
<td>11.8</td>
<td>6</td>
<td>82</td>
</tr>
<tr>
<td>TB</td>
<td>46.8</td>
<td>76</td>
<td>22.2</td>
<td>6</td>
<td>86</td>
</tr>
<tr>
<td>Pleural Effusion</td>
<td>41.1</td>
<td>214</td>
<td>27.8</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>Chest Infection</td>
<td>51.9</td>
<td>46</td>
<td>26.3</td>
<td>0</td>
<td>88</td>
</tr>
<tr>
<td>Lungs cancer</td>
<td>59.7</td>
<td>19</td>
<td>14.4</td>
<td>27</td>
<td>81</td>
</tr>
<tr>
<td>Cancer</td>
<td>65.1</td>
<td>29</td>
<td>12.1</td>
<td>28</td>
<td>81</td>
</tr>
<tr>
<td>Others</td>
<td>41.4</td>
<td>68</td>
<td>29.7</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Total</td>
<td>44.4</td>
<td>11233</td>
<td>30.3</td>
<td>0</td>
<td>105</td>
</tr>
</tbody>
</table>
**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**

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Diseases</td>
<td>4682861.099</td>
<td>12</td>
<td>390238.425</td>
<td>780.794</td>
<td>.000</td>
</tr>
<tr>
<td>Within Diseases</td>
<td>5607720.481</td>
<td>11220</td>
<td>499.797</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10290581.580</td>
<td>11232</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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**

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

**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

<table>
<thead>
<tr>
<th>Disease</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not ARI</td>
<td>6181</td>
<td>54.6</td>
<td>54.6</td>
</tr>
<tr>
<td>Lower</td>
<td>416</td>
<td>3.7</td>
<td>58.3</td>
</tr>
<tr>
<td>Upper</td>
<td>55</td>
<td>0.5</td>
<td>58.8</td>
</tr>
<tr>
<td>Unspecified</td>
<td>1192</td>
<td>10.5</td>
<td>69.3</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>3293</td>
<td>29.1</td>
<td>98.4</td>
</tr>
<tr>
<td>Tonsillitis</td>
<td>70</td>
<td>0.6</td>
<td>99.0</td>
</tr>
<tr>
<td>Otitis Media</td>
<td>111</td>
<td>1.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Sinusitis</td>
<td>2</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Common Cold</td>
<td>1</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>11321</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

**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

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

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

Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Interpretation / Assessment

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

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

<table>
<thead>
<tr>
<th>Disease</th>
<th>PM$_{2.5}$</th>
<th>CO</th>
<th>NO$_2$</th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>.088</td>
<td>-.466</td>
<td>-.078</td>
<td>.270</td>
<td>-.562</td>
<td>-.224</td>
</tr>
<tr>
<td>Respiratory (Address KTM valley)</td>
<td>.043</td>
<td>-.480</td>
<td>-.103</td>
<td>.283</td>
<td>-.559</td>
<td>-.198</td>
</tr>
<tr>
<td>ARI</td>
<td>-.215</td>
<td>-.606*</td>
<td>-.355</td>
<td>.471</td>
<td>-.269</td>
<td>-.016</td>
</tr>
<tr>
<td>ARI (Address KTM valley)</td>
<td>-.217</td>
<td>-.527</td>
<td>-.303</td>
<td>.475</td>
<td>-.290</td>
<td>-.059</td>
</tr>
<tr>
<td>COPD</td>
<td>.446</td>
<td>-.152</td>
<td>.371</td>
<td>-.032</td>
<td>-.788**</td>
<td>-.606*</td>
</tr>
<tr>
<td>COPD (Address KTM valley)</td>
<td>.445</td>
<td>-.168</td>
<td>.395</td>
<td>-.049</td>
<td>-.838**</td>
<td>-.609*</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>.090</td>
<td>-.475</td>
<td>-.069</td>
<td>.233</td>
<td>-.478</td>
<td>-.334</td>
</tr>
<tr>
<td>Pneumonia (Address KTM valley)</td>
<td>.126</td>
<td>-.395</td>
<td>-.004</td>
<td>.172</td>
<td>-.425</td>
<td>-.447</td>
</tr>
<tr>
<td>Respiratory_Age≤19</td>
<td>-.485</td>
<td>-.534</td>
<td>-.632*</td>
<td>.319</td>
<td>.311</td>
<td>.505</td>
</tr>
<tr>
<td>Respiratory_Age≤19 (Address KTM valley)</td>
<td>-.508</td>
<td>-.582*</td>
<td>-.629*</td>
<td>.407</td>
<td>.174</td>
<td>.507</td>
</tr>
<tr>
<td>Respiratory_Age≥50</td>
<td>.401</td>
<td>-.254</td>
<td>.255</td>
<td>.017</td>
<td>-.716**</td>
<td>-.467</td>
</tr>
<tr>
<td>Respiratory_Age≥50 (Address KTM valley)</td>
<td>.414</td>
<td>-.240</td>
<td>.296</td>
<td>.009</td>
<td>-.797**</td>
<td>-.511</td>
</tr>
</tbody>
</table>

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 hospitalizations 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

<table>
<thead>
<tr>
<th>Response Variables</th>
<th>Main Explanatory Variables</th>
<th>Confounders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory hospitalizations (All respiratory ailments including chest, lungs, Cancer, TB, etc.)</td>
<td>Ambient PM$_{2.5}$</td>
<td>Air temperature</td>
</tr>
<tr>
<td>COPD hospitalizations</td>
<td>Ambient CO</td>
<td>Relative humidity</td>
</tr>
<tr>
<td>ARI hospitalizations</td>
<td>Ambient NO$_{2}$</td>
<td>Rainfall</td>
</tr>
<tr>
<td>Pneumonia hospitalizations</td>
<td></td>
<td>Season</td>
</tr>
<tr>
<td>Age-specific respiratory hospitalizations</td>
<td></td>
<td>Day of week (Saturday)</td>
</tr>
<tr>
<td>Address-specific hospitalizations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-cause mortality (non-accidental)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model</th>
<th>All addresses included</th>
<th>Address Kathmandu Valley</th>
<th>Autoregressive (All addresses)</th>
<th>Autoregressive (Kathmandu address)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>COPD</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>ARI</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Respiratory (age≤19)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Respiratory (age≥50)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>All Cause mortality</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>25</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Detection</th>
<th>Method</th>
<th>Criteria</th>
<th>Preferred p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Omnibus test</td>
<td>Statistical significance</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Normality</td>
<td>Kolmogorov-Smirnov (K-S) test</td>
<td>Statistical insignificance</td>
<td>&gt;0.01</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>Variance inflation factors (VIFs)</td>
<td>Low value</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Residual plot</td>
<td>Randomly distributed in constant band</td>
<td>-</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram up to 7th lag</td>
<td>Statistical insignificance</td>
<td>&gt;0.01</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.404</td>
<td>.1492</td>
<td>3.112 3.697</td>
<td>520.940 1 .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.366</td>
<td>.0309</td>
<td>.305 .426</td>
<td>140.032 1 .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>0.0014</td>
<td>.0004</td>
<td>.001 .002</td>
<td>10.626 1 .001</td>
</tr>
<tr>
<td>Temperature$_0$</td>
<td>0.0091</td>
<td>.0025</td>
<td>.004 .014</td>
<td>13.568 1 .000</td>
</tr>
<tr>
<td>Relative Humidity$_0$</td>
<td>-0.0129</td>
<td>.0024</td>
<td>-.018 -.008</td>
<td>28.994 1 .000</td>
</tr>
<tr>
<td>Rainfall$_0$</td>
<td>-0.0034</td>
<td>.0015</td>
<td>-.006 .000</td>
<td>5.206 1 .023</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Difference</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>0.0014</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.014</td>
<td>1.41</td>
</tr>
<tr>
<td>Temperature$_0$</td>
<td>0.0091</td>
<td>1</td>
<td>° Celsius</td>
<td>1.009</td>
<td>0.91</td>
</tr>
<tr>
<td>Relative Humidity$_0$</td>
<td>-0.0129</td>
<td>1</td>
<td>%</td>
<td>0.987</td>
<td>-1.28</td>
</tr>
<tr>
<td>Rainfall$_0$</td>
<td>-0.0034</td>
<td>1</td>
<td>mm</td>
<td>0.997</td>
<td>-0.34</td>
</tr>
<tr>
<td>Not Saturday</td>
<td>0.366</td>
<td>1</td>
<td>Categorical</td>
<td>1.442</td>
<td>44.20</td>
</tr>
</tbody>
</table>
Table 36: Respiratory effect model (all addresses inclusive): Model adequacy tests

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

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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>2.750</td>
<td>.1735</td>
<td>2.410</td>
<td>3.090</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.356</td>
<td>.0335</td>
<td>.290</td>
<td>.422</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM_{2.5}</td>
<td>.0010</td>
<td>.0005</td>
<td>3.767E-005</td>
<td>.002</td>
</tr>
<tr>
<td>Temperature_0</td>
<td>.0064</td>
<td>.0025</td>
<td>.001</td>
<td>.011</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0058</td>
<td>.0026</td>
<td>-.011</td>
<td>-.001</td>
</tr>
<tr>
<td>Rainfall_0</td>
<td>-.0034</td>
<td>.0015</td>
<td>-.006</td>
<td>.000</td>
</tr>
<tr>
<td>Respiratory_1</td>
<td>.0053</td>
<td>.0011</td>
<td>.003</td>
<td>.007</td>
</tr>
<tr>
<td>Respiratory_2</td>
<td>.0046</td>
<td>.0011</td>
<td>.003</td>
<td>.007</td>
</tr>
<tr>
<td>Respiratory_7</td>
<td>.0041</td>
<td>.0011</td>
<td>.002</td>
<td>.006</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Difference</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM_{2.5}</td>
<td>0.0010</td>
<td>10</td>
<td>µg/m³</td>
<td>1.010</td>
<td>1.01</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.0064</td>
<td>1</td>
<td>° Celsius</td>
<td>1.006</td>
<td>0.64</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>-0.0058</td>
<td>1</td>
<td>%</td>
<td>0.994</td>
<td>-0.58</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.0034</td>
<td>1</td>
<td>mm</td>
<td>0.997</td>
<td>-0.34</td>
</tr>
<tr>
<td>Non-Saturdays</td>
<td>0.356</td>
<td>1</td>
<td>categorical</td>
<td>1.428</td>
<td>42.76</td>
</tr>
</tbody>
</table>
Table 39: Autoregressive respiratory effect model (all addresses inclusive): Model adequacy tests

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=1021.4 at 357 df; Residual Deviance:695.4 at 349 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: (325.9 at 8 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;2.7</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram up to 7th lag</td>
<td>Autocorrelations insignificant</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.21; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.083</td>
<td>.1845</td>
<td>2.722-3.445</td>
<td>279.384, 1, .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.370</td>
<td>.0383</td>
<td>.295-2.45</td>
<td>93.115, 1, .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM_{2.5} 0</td>
<td>.0014</td>
<td>.0005</td>
<td>.000-0.003</td>
<td>7.239, 1, .007</td>
</tr>
<tr>
<td>Temperature_0</td>
<td>.0102</td>
<td>.0031</td>
<td>.004-0.016</td>
<td>11.223, 1, .001</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0162</td>
<td>.0029</td>
<td>-.022-0.010</td>
<td>30.092, 1, .000</td>
</tr>
<tr>
<td>Rainfall_0</td>
<td>-.0035</td>
<td>.0019</td>
<td>-.007-0.000</td>
<td>3.399, 1, .065</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Difference</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>0.0014</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.014</td>
<td>1.41</td>
</tr>
<tr>
<td>Temperature _0</td>
<td>0.0102</td>
<td>1</td>
<td>°Celsius</td>
<td>1.010</td>
<td>1.03</td>
</tr>
<tr>
<td>Relative Humidity _0</td>
<td>-0.0162</td>
<td>1</td>
<td>%</td>
<td>0.984</td>
<td>-1.61</td>
</tr>
<tr>
<td>Rainfall _0</td>
<td>-0.0035</td>
<td>1</td>
<td>mm</td>
<td>0.997</td>
<td>-0.35</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.37</td>
<td>1</td>
<td>-</td>
<td>1.448</td>
<td>44.77</td>
</tr>
</tbody>
</table>

*Categorical variable

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;2.5</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram up to 7th lag</td>
<td>Slightly significant autocorrelations at 1, 2, 5 and 6 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.17; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

The graphs above illustrate the relationship between the predicted value of the mean of the response and the standardized Pearson residual and the standardized deviance residual, respectively.
Figure 37: Respiratory effect model (address Kathmandu Valley): Model adequacy tests
3.3.1.4 Autoregressive respiratory effect model (address Kathmandu Valley)

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

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

<table>
<thead>
<tr>
<th>Parameter Estimates</th>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
<td>Wald Chi-Square</td>
</tr>
<tr>
<td>(Intercept)</td>
<td></td>
<td>2.285</td>
<td>.2150</td>
<td>1.864</td>
<td>2.707</td>
<td>112.944</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td></td>
<td>.411</td>
<td>.0394</td>
<td>.334</td>
<td>.489</td>
<td>109.286</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td></td>
<td>0*</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td></td>
<td>.0010</td>
<td>.0006</td>
<td>0</td>
<td>.002</td>
<td>3.338</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td>.0068</td>
<td>.0031</td>
<td>.001</td>
<td>.013</td>
<td>4.851</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td></td>
<td>-.0070</td>
<td>.0032</td>
<td>-.013</td>
<td>-.001</td>
<td>4.683</td>
</tr>
<tr>
<td>Rainfall</td>
<td></td>
<td>-.0032</td>
<td>.0019</td>
<td>-.007</td>
<td>.001</td>
<td>2.859</td>
</tr>
<tr>
<td>Respiratory</td>
<td></td>
<td>.0061</td>
<td>.0017</td>
<td>.003</td>
<td>.010</td>
<td>12.625</td>
</tr>
<tr>
<td>Respiratory</td>
<td></td>
<td>.0076</td>
<td>.0017</td>
<td>.004</td>
<td>.011</td>
<td>19.247</td>
</tr>
<tr>
<td>Respiratory</td>
<td></td>
<td>.0088</td>
<td>.0017</td>
<td>.005</td>
<td>.012</td>
<td>26.331</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;2.6</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Absence of significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.24; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Respiratory % lag</th>
<th>Respiratory % (Autoregressive)</th>
<th>Respiratory KTM % lag</th>
<th>Respiratory KTM % (Autoregressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>1.014 (0.001)</td>
<td>0.101 (0.04)</td>
<td>1.41 (0.007)</td>
<td>1.01 (0.068)</td>
</tr>
<tr>
<td>CO</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Temperature</td>
<td>1.01 (0.000)</td>
<td>0.64 (0.01)</td>
<td>1.03 (0.001)</td>
<td>0.68 (0.03)</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>-1.28 (0.03)</td>
<td>-0.58 (0.03)</td>
<td>-1.61 (0.000)</td>
<td>-0.70 (0.03)</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.34 (0.023)</td>
<td>-0.34 (0.025)</td>
<td>-0.35 (0.065)</td>
<td>-0.32 (0.09)</td>
</tr>
<tr>
<td>Non-Saturday</td>
<td>44.2 (0.000)</td>
<td>42.8 (0.000)</td>
<td>44.8 (0.000)</td>
<td>50.8 (0.000)</td>
</tr>
<tr>
<td>Autoregressive Lag effects</td>
<td>-</td>
<td>-</td>
<td>1, 2, 7 (+)</td>
<td>-</td>
</tr>
</tbody>
</table>

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°C 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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Wald Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.462</td>
<td>.1554</td>
<td>3.157</td>
<td>3.766</td>
<td>496.004</td>
<td>1</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.424</td>
<td>.0504</td>
<td>.325</td>
<td>.523</td>
<td>70.677</td>
<td>1</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0</td>
<td>. .</td>
<td>. .</td>
<td>. .</td>
<td>. .</td>
<td>. .</td>
</tr>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>.0014</td>
<td>.0005</td>
<td>.000</td>
<td>.002</td>
<td>7.155</td>
<td>1</td>
</tr>
<tr>
<td>Relative Humidity _0</td>
<td>-.0328</td>
<td>.0034</td>
<td>-.039</td>
<td>-.026</td>
<td>94.463</td>
<td>1</td>
</tr>
<tr>
<td>Rainfall _0</td>
<td>-.0071</td>
<td>.0026</td>
<td>-.012</td>
<td>-.002</td>
<td>7.645</td>
<td>1</td>
</tr>
<tr>
<td>NO$_2$ _2 (mean)</td>
<td>.1147</td>
<td>.0641</td>
<td>-.011</td>
<td>.240</td>
<td>3.206</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>0.0014</td>
<td>10 µg/m$^3$</td>
<td>1.014</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ _2 (mean)</td>
<td>0.1147</td>
<td>1 mg/m$^3$</td>
<td>1.122</td>
<td>12.15</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity _0</td>
<td>-.0328</td>
<td>1 %</td>
<td>0.968</td>
<td>-3.23</td>
<td></td>
</tr>
<tr>
<td>Rainfall _0</td>
<td>-.0071</td>
<td>1 mm</td>
<td>0.993</td>
<td>-0.71</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.424</td>
<td>1 -</td>
<td>1.528</td>
<td>52.81</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=844.1 at 363 df; Residual Deviance:605.6 at 358 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: (238.6 at 5 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;1.4</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Slightly significant autocorrelations at 1 and 2 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.61; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \beta )</th>
<th>Std. Error</th>
<th>Lower</th>
<th>Upper</th>
<th>Wald Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2.549</td>
<td>.1998</td>
<td>2.157</td>
<td>2.940</td>
<td>162.668</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.436</td>
<td>.0505</td>
<td>.337</td>
<td>.535</td>
<td>74.574</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0 ( ^a )</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(_{2.5})</td>
<td>.0010</td>
<td>.0005</td>
<td>-9.590E-005</td>
<td>.002</td>
<td>3.174</td>
<td>1</td>
<td>.075</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0197</td>
<td>.0038</td>
<td>-.027</td>
<td>-.012</td>
<td>26.260</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>Rainfall_0</td>
<td>-.0054</td>
<td>.0026</td>
<td>-.010</td>
<td>.000</td>
<td>4.384</td>
<td>1</td>
<td>.036</td>
</tr>
<tr>
<td>NO(_2) (mean)</td>
<td>.0859</td>
<td>.0641</td>
<td>-.040</td>
<td>.211</td>
<td>1.797</td>
<td>1</td>
<td>.180</td>
</tr>
<tr>
<td>COPD_1</td>
<td>.0115</td>
<td>.0030</td>
<td>.006</td>
<td>.017</td>
<td>14.327</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>COPD_2</td>
<td>.0172</td>
<td>.0030</td>
<td>.011</td>
<td>.023</td>
<td>32.100</td>
<td>1</td>
<td>.000</td>
</tr>
</tbody>
</table>

\( ^a \) 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**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>0.001</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>NO$_2$ (mean)</td>
<td>0.0859</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>1.09</td>
<td>8.97</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>-0.0197</td>
<td>1</td>
<td>%</td>
<td>0.98</td>
<td>-1.95</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.0054</td>
<td>1</td>
<td>mm</td>
<td>0.99</td>
<td>-0.54</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.436</td>
<td>1</td>
<td>-</td>
<td>1.54</td>
<td>54.65</td>
</tr>
</tbody>
</table>

*Categorical variable

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

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=843.1 at 362 df; Residual Deviance:550 at 356 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: ( 291.1 at 6 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;1.5</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.86; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.170</td>
<td>.1941</td>
<td>2.790 3.551</td>
<td>266.760 1 .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.398</td>
<td>.0621</td>
<td>.277  .520</td>
<td>41.111 1 .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>. . .</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0367</td>
<td>.0042</td>
<td>-.045 -.029</td>
<td>78.039 1 .000</td>
</tr>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>.0016</td>
<td>.0007</td>
<td>.000  .003</td>
<td>4.947 1 .026</td>
</tr>
<tr>
<td>NO$_2$ _7 (mean)</td>
<td>.2706</td>
<td>.1398</td>
<td>-.003  .545</td>
<td>3.748 1 .053</td>
</tr>
<tr>
<td>a. Set to zero because this parameter is redundant.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>0.0016</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.020</td>
<td>2.02</td>
</tr>
<tr>
<td>NO$_2$ _7 (mean)</td>
<td>0.2706</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>1.311</td>
<td>31.13</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0367</td>
<td>1</td>
<td>%</td>
<td>0.964</td>
<td>-3.63</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.398</td>
<td>1</td>
<td>-</td>
<td>1.489</td>
<td>48.88</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=645 at 387 df; Residual Deviance:481.2 at 353 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: (163.8 at 4 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;1.6</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Slightly significant autocorrelations at 1, 2 and 5 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.72; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
3.3.2.4 Autoregressive COPD effect model (address Kathmandu Valley)

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

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ -0</td>
<td>0.0013</td>
<td>10 µg/m$^3$</td>
<td>1.013</td>
<td>1.31</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ -7 (mean)</td>
<td>0.2321</td>
<td>1 mg/m$^3$</td>
<td>1.261</td>
<td>26.12</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>-0.0266</td>
<td>1 %</td>
<td>0.974</td>
<td>-2.62</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.391</td>
<td>1</td>
<td>1.478</td>
<td>47.85</td>
<td></td>
</tr>
</tbody>
</table>

*a. Categorical variable
Autoregressive COPD effect model (address Kathmandu Valley): Model adequacy tests

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs &lt;1.6</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p = 0.56; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Particular</th>
<th>COPD</th>
<th>COPD (Autoregressive)</th>
<th>COPD KTM</th>
<th>COPD KTM (Autoregressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>1.41 (0.01)</td>
<td>1.01 (0.07)</td>
<td>2.02 (0.03)</td>
<td>1.31 (0.07)</td>
</tr>
<tr>
<td>CO</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>NO$_{2}$</td>
<td>12.15 (0.07)</td>
<td>8.97 (0.18)</td>
<td>31.13 (0.05)</td>
<td>26.12 (0.10)</td>
</tr>
<tr>
<td>Temperature</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Relative</td>
<td>-3.23 (0.00)</td>
<td>-1.95 (0.00)</td>
<td>-3.63 (0.00)</td>
<td>-2.62 (0.00)</td>
</tr>
<tr>
<td>Humidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.71 (0.01)</td>
<td>-0.54 (0.04)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Non-Saturday</td>
<td>52.8 (0.00)</td>
<td>54.6 (0.00)</td>
<td>48.9 (0.00)</td>
<td>47.9 (0.00)</td>
</tr>
<tr>
<td>Autoregressive</td>
<td>-</td>
<td>-</td>
<td>1, 2 (+)</td>
<td>-</td>
</tr>
<tr>
<td>Lag effects</td>
<td></td>
<td></td>
<td></td>
<td>1, 2 (+)</td>
</tr>
</tbody>
</table>

Interpretation / Assessment

When considering the percentage change in COPD hospital admissions per 10 µg/m³ 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/m³ 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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.982</td>
<td>.1406</td>
<td>1.706 - 2.257</td>
<td>Wald Chi-Square: 198.731, df: 1, Sig: .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.319</td>
<td>.0453</td>
<td>.230 - .408</td>
<td>Wald Chi-Square: 49.583, df: 1, Sig: .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$ (Geo)</td>
<td>0.0027</td>
<td>.0009</td>
<td>.001 - .004</td>
<td>Wald Chi-Square: 9.434, df: 1, Sig: .002</td>
</tr>
<tr>
<td>CO$_7$ (AM)</td>
<td>-0.1232</td>
<td>.0517</td>
<td>-0.225 - 0.022</td>
<td>Wald Chi-Square: 5.674, df: 1, Sig: .017</td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-0.3535</td>
<td>.1210</td>
<td>-0.591 - 0.116</td>
<td>Wald Chi-Square: 8.541, df: 1, Sig: .003</td>
</tr>
<tr>
<td>Temperature$_7$ (Mean)</td>
<td>0.0182</td>
<td>.0041</td>
<td>.010 - .026</td>
<td>Wald Chi-Square: 19.662, df: 1, Sig: .000</td>
</tr>
<tr>
<td>Rainfall$_7$ (mean)</td>
<td>0.0127</td>
<td>.0040</td>
<td>.010 - .020</td>
<td>Wald Chi-Square: 10.302, df: 1, Sig: .001</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ (Geo)</td>
<td>0.0027</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.027</td>
<td>2.74</td>
</tr>
<tr>
<td>CO$_7$ (AM)</td>
<td>-0.1232</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>0.884</td>
<td>-11.59</td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-0.3535</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>0.702</td>
<td>-29.78</td>
</tr>
<tr>
<td>Temperature$_7$ (Mean)</td>
<td>0.0182</td>
<td>1</td>
<td>-</td>
<td>1.018</td>
<td>1.84</td>
</tr>
<tr>
<td>Rainfall$_7$ (Mean)</td>
<td>-0.0127</td>
<td>1</td>
<td>%</td>
<td>0.987</td>
<td>-1.26</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.319</td>
<td>1</td>
<td>-</td>
<td>1.376</td>
<td>37.58</td>
</tr>
</tbody>
</table>

*a. Set to zero because this parameter is redundant.*
Table 62: ARI effect model (all addresses inclusive): Model adequacy tests

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta$</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>1.530</td>
<td>.1368</td>
<td>1.261</td>
<td>1.798</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.337</td>
<td>.0460</td>
<td>.247</td>
<td>.428</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$ (Geo)</td>
<td>.0028</td>
<td>.0008</td>
<td>.001</td>
<td>.004</td>
</tr>
<tr>
<td>Temperature$_7$ (Mean)</td>
<td>.0131</td>
<td>.0042</td>
<td>.005</td>
<td>.021</td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-.2570</td>
<td>.1185</td>
<td>-.489</td>
<td>-.025</td>
</tr>
<tr>
<td>ARI$_1$</td>
<td>.0144</td>
<td>.0029</td>
<td>.009</td>
<td>.020</td>
</tr>
<tr>
<td>ARI$_3$</td>
<td>.0114</td>
<td>.0029</td>
<td>.006</td>
<td>.017</td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ 7 (Geo)</td>
<td>0.0028</td>
<td>10 µg/m³</td>
<td>1.028</td>
<td>2.84</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ 7 (AM)</td>
<td>-0.257</td>
<td>1 mg/m³</td>
<td>0.773</td>
<td>-22.66</td>
<td></td>
</tr>
<tr>
<td>Temperature 7 (Mean)</td>
<td>0.0131</td>
<td>1 °C</td>
<td>1.013</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays’</td>
<td>0.337</td>
<td>1</td>
<td>1.401</td>
<td>40.07</td>
<td></td>
</tr>
</tbody>
</table>

*Categorical variable*

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt; 3.2</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.78; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.294</td>
<td>.1569</td>
<td>.987 1.602</td>
<td>68.030</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.347</td>
<td>.0577</td>
<td>.234 .460</td>
<td>36.194</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0†</td>
<td>.</td>
<td>. .</td>
<td>. .</td>
</tr>
<tr>
<td>NO₂_7 (Geo)</td>
<td>-.2946</td>
<td>.1329</td>
<td>-.555 -.034</td>
<td>4.911</td>
</tr>
<tr>
<td>Temperature_7 (Geo)</td>
<td>.0239</td>
<td>.0048</td>
<td>.014 .033</td>
<td>24.478</td>
</tr>
<tr>
<td>Rainfall_7 (Geo)</td>
<td>-.0109</td>
<td>.0042</td>
<td>-.019 -.003</td>
<td>6.685</td>
</tr>
<tr>
<td>PM_2 (Mean)</td>
<td>.0027</td>
<td>.0009</td>
<td>.001 .005</td>
<td>8.790</td>
</tr>
</tbody>
</table>

a. Set to zero because this parameter is redundant.

Distributed lag effects of PM_{2.5} (2 day mean effect), NO₂ (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, NO₂ 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)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM_{2.5} (Mean)</td>
<td>0.0027</td>
<td>10 µg/m³</td>
<td></td>
<td>1.027</td>
<td>2.74</td>
</tr>
<tr>
<td>NO₂_7 (Geo)</td>
<td>-0.2946</td>
<td>1 mg/m³</td>
<td></td>
<td>0.745</td>
<td>-25.52</td>
</tr>
<tr>
<td>Temperature_7 (Geo)</td>
<td>0.0239</td>
<td>1 °C</td>
<td></td>
<td>1.024</td>
<td>2.42</td>
</tr>
<tr>
<td>Rainfall_7 (Geo)</td>
<td>-0.0109</td>
<td>1 mm</td>
<td></td>
<td>0.989</td>
<td>-1.08</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.337</td>
<td>1</td>
<td></td>
<td>1.415</td>
<td>41.48</td>
</tr>
</tbody>
</table>

*Categorical variable
### Table 68: ARI effect model (address Kathmandu valley): Model adequacy tests

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=583.4 at 357 df; Residual Deviance:502.4 at 352 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: ( 81.1 at 5 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIfs&lt; 2.8</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Slight significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>autocorrelations at lags 1, 2, 3, 5 and 7</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.62; normal q-q plot</td>
<td>Deviance residual normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>.886</td>
<td>.1520</td>
<td>.588 1.184</td>
<td>33.955 1 .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.334</td>
<td>.0600</td>
<td>.216 .451</td>
<td>30.913 1 .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0*</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$ (Mean)</td>
<td>.0020</td>
<td>.0008</td>
<td>.000 0.004</td>
<td>5.920 1 .015</td>
</tr>
<tr>
<td>Temperature$_7$ (Geo)</td>
<td>.0142</td>
<td>.0049</td>
<td>.005 .024</td>
<td>8.430 1 .004</td>
</tr>
<tr>
<td>ARI$_1$</td>
<td>.0169</td>
<td>.0049</td>
<td>.007 .026</td>
<td>12.178 1 .000</td>
</tr>
<tr>
<td>ARI$_3$</td>
<td>.0159</td>
<td>.0048</td>
<td>.006 .025</td>
<td>10.960 1 .001</td>
</tr>
<tr>
<td>ARI$_5$</td>
<td>.0174</td>
<td>.0049</td>
<td>.008 .027</td>
<td>12.865 1 .000</td>
</tr>
<tr>
<td>ARI$_7$</td>
<td>.0141</td>
<td>.0050</td>
<td>.004 .024</td>
<td>8.123 1 .004</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ (Mean)</td>
<td>0.002</td>
<td>10</td>
<td>μg/m$^3$</td>
<td>1.020</td>
<td>2.02</td>
</tr>
<tr>
<td>Temperature$_7$ (Geo)</td>
<td>0.0142</td>
<td>1</td>
<td>%C</td>
<td>1.014</td>
<td>1.43</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.334</td>
<td>1</td>
<td>–</td>
<td>1.397</td>
<td>39.65</td>
</tr>
</tbody>
</table>

*Categorical variable

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
</tbody>
</table>
### Multicollinearity
- **VIFs < 2.5**
- **No multicollinearity**

### Heteroscedasticity
- 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**
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
3.3.3.5 Comparative assessment between ARI effect GLMs

Table 72: Comparative assessment between ARI effect GLMs

<table>
<thead>
<tr>
<th>Particular</th>
<th>ARI (Autoregressive)</th>
<th>ARI</th>
<th>ARI KTM (Autoregressive)</th>
<th>ARI KTM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>2.74 (&lt;0.01) 7 day Geometric lag</td>
<td>2.84 (&lt;0.01) 7 day Geometric lag</td>
<td>2.74 (&lt;0.01) 2 day mean</td>
<td>2.02 (&lt;0.02) 2 day mean</td>
</tr>
<tr>
<td>CO</td>
<td>-11.6 (0.02) 7 day AM lag</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NO$_{2}$</td>
<td>-29.8 (&lt;0.01) 7 day AM lag</td>
<td>-22.7 (0.03) 7 day AM lag</td>
<td>-25.5 (&lt;0.03) 7 day Geometric lag</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure: 46 Autoregressive ARI effect model (address Kathmandu valley): Model adequacy tests
<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Relative Humidity</th>
<th>Rainfall</th>
<th>Non-Saturday</th>
<th>Autoregressive Lag effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.84 (0.00)</td>
<td>X</td>
<td>-1.26 (&lt;0.01)</td>
<td>37.6 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td>7 day mean</td>
<td>1.32 (&lt;0.01)</td>
<td>X</td>
<td>-</td>
<td>40.1 (0.00)</td>
<td>1, 3, 5</td>
</tr>
<tr>
<td>Geometric lag</td>
<td>2.42 (0.00)</td>
<td>X</td>
<td>-1.08 (0.01)</td>
<td>41.5 (0.00)</td>
<td>(+); 4</td>
</tr>
<tr>
<td></td>
<td>1.43 (&lt;0.01)</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Interpretation / Assessment**

Comparing the percent change in ARI hospital admissions per 10 µg/m³ 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°C 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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>1.283</td>
<td>.1749</td>
<td>.940</td>
<td>1.626</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.392</td>
<td>.0584</td>
<td>.278</td>
<td>.507</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM$_{2.5}$ (AM)</td>
<td>.0046</td>
<td>.0011</td>
<td>.002</td>
<td>.007</td>
</tr>
<tr>
<td>CO$_4$ (AM)</td>
<td>-.108</td>
<td>.0547</td>
<td>-.215</td>
<td>-.001</td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-.2549</td>
<td>.1503</td>
<td>-.550</td>
<td>.040</td>
</tr>
<tr>
<td>Temperature (AM)</td>
<td>.0213</td>
<td>.0051</td>
<td>.011</td>
<td>.031</td>
</tr>
<tr>
<td>Rainfall (AM)</td>
<td>-.0131</td>
<td>.0049</td>
<td>-.023</td>
<td>-.004</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ (AM)</td>
<td>0.0046</td>
<td>10 µg/m$^3$</td>
<td>1.047</td>
<td>4.71</td>
<td></td>
</tr>
<tr>
<td>CO$_4$ (AM)</td>
<td>-.108</td>
<td>1 mg/m$^3$</td>
<td>0.898</td>
<td>-10.24</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-.2549</td>
<td>1 mg/m$^3$</td>
<td>0.775</td>
<td>-22.50</td>
<td></td>
</tr>
<tr>
<td>Temperature (AM)</td>
<td>0.0213</td>
<td>1 °C</td>
<td>1.022</td>
<td>2.15</td>
<td></td>
</tr>
<tr>
<td>Rainfall (AM)</td>
<td>-.0131</td>
<td>1 mm</td>
<td>0.987</td>
<td>-1.30</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.392</td>
<td>1</td>
<td>1.480</td>
<td>47.99</td>
<td></td>
</tr>
</tbody>
</table>

*Categorical variable
### Table 75: Pneumonia effect model (all addresses inclusive): Model adequacy tests

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;3.8</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>significant autocorrelations at 1, 3 and 5 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.89; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>.917</td>
<td>.1628</td>
<td>.598 1.236</td>
<td>31.727 1 .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.394</td>
<td>.0586</td>
<td>.279  .509</td>
<td>45.286 1 .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0^a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM_{2.5} (AM)</td>
<td>.0032</td>
<td>.0010</td>
<td>.001  .005</td>
<td>10.975 1 .001</td>
</tr>
<tr>
<td>Temperature_{7} (AM)</td>
<td>.0150</td>
<td>.0052</td>
<td>.005  .025</td>
<td>8.367 1 .004</td>
</tr>
<tr>
<td>Pneumonia_{1}</td>
<td>.0187</td>
<td>.0050</td>
<td>.009  .028</td>
<td>14.203 1 .000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$_7 (AM)</td>
<td>0.0032</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.033</td>
<td>3.25</td>
</tr>
<tr>
<td>Temperature_7 (AM)</td>
<td>0.015</td>
<td>1</td>
<td>°C</td>
<td>1.015</td>
<td>1.51</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.394</td>
<td>1</td>
<td>-</td>
<td>1.483</td>
<td>48.29</td>
</tr>
</tbody>
</table>

*a. Categorical variable*

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=518.4 at 357 df; Residual Deviance=404.7 at 351 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: (113.7 at 6 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;3</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.98; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>.922</td>
<td>.2054</td>
<td>.519</td>
<td>1.325</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.356</td>
<td>.0721</td>
<td>.215</td>
<td>.497</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>. .</td>
<td>. .</td>
<td>. .</td>
</tr>
<tr>
<td>PM$_{2.5}$ (Geo)</td>
<td>.0035</td>
<td>.0012</td>
<td>.001</td>
<td>.006</td>
</tr>
<tr>
<td>CO$_7$ (Geo)</td>
<td>-.1421</td>
<td>.0731</td>
<td>-.285</td>
<td>.001</td>
</tr>
<tr>
<td>Temperature$_7$ (Geo)</td>
<td>.0202</td>
<td>.060</td>
<td>.008</td>
<td>.032</td>
</tr>
<tr>
<td>Rainfall$_7$ (Geo)</td>
<td>-.0165</td>
<td>.055</td>
<td>-.027</td>
<td>-.006</td>
</tr>
</tbody>
</table>

a. Set to zero because this parameter is redundant.

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ (Geo)</td>
<td>0.0035</td>
<td>10 µg/m³</td>
<td>1.036</td>
<td>3.56</td>
<td></td>
</tr>
<tr>
<td>CO$_7$ (Geo)</td>
<td>-0.1421</td>
<td>1 mg/m³</td>
<td>0.868</td>
<td>-13.25</td>
<td></td>
</tr>
<tr>
<td>Temperature$_7$ (Geo)</td>
<td>0.0202</td>
<td>1 °C</td>
<td>1.020</td>
<td>2.04</td>
<td></td>
</tr>
<tr>
<td>Rain$_7$ (Geo)</td>
<td>-0.0165</td>
<td>1 mm</td>
<td>0.984</td>
<td>-1.64</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.356</td>
<td>1 -</td>
<td>1.428</td>
<td>42.76</td>
<td></td>
</tr>
</tbody>
</table>

*Categorical variable

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

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

![Standardized Pearson Residual vs Predicted Value of Mean of Response](image.png)
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \beta )</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>.484</td>
<td>.1953</td>
<td>.101 .867</td>
<td>6.137 1 .013</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.395</td>
<td>.0725</td>
<td>.253 .537</td>
<td>29.700 1 .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>. .</td>
<td>. .</td>
<td>. .</td>
</tr>
<tr>
<td>PM_{2.5} (Geo)</td>
<td>.0033</td>
<td>.0011</td>
<td>.001 .006</td>
<td>8.306 1 .004</td>
</tr>
<tr>
<td>Temperature_{7} (Geo)</td>
<td>.0137</td>
<td>.0061</td>
<td>.002 .026</td>
<td>5.017 1 .025</td>
</tr>
<tr>
<td>Pneumonia_1</td>
<td>.0301</td>
<td>.0083</td>
<td>.014 .046</td>
<td>13.304 1 .000</td>
</tr>
<tr>
<td>Pneumonia_2</td>
<td>.0224</td>
<td>.0082</td>
<td>.006 .038</td>
<td>7.457 1 .006</td>
</tr>
<tr>
<td>Pneumonia_5</td>
<td>.0231</td>
<td>.0082</td>
<td>.007 .039</td>
<td>7.875 1 .005</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$-7 (Geo)</td>
<td>0.0033</td>
<td>10 µg/m$^3$</td>
<td>1.034</td>
<td>3.36</td>
<td></td>
</tr>
<tr>
<td>Temperature-7 (Geo)</td>
<td>0.0137</td>
<td>1 °C</td>
<td>1.014</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.395</td>
<td>1</td>
<td>1.484</td>
<td>48.44</td>
<td></td>
</tr>
</tbody>
</table>

*Categorical variable

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;2.7</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.62; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Not detected</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Pneumonia (Autoregressive)</th>
<th>Pneumonia KTM</th>
<th>Pneumonia KTM (Autoregressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>lag</td>
<td>%</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>4.71 (0.00)</td>
<td>7 day AM lag</td>
<td>3.25 (&lt;0.01)</td>
</tr>
<tr>
<td>CO</td>
<td>-10.24 (0.05)</td>
<td>7 day AM lag</td>
<td>X</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>-22.5 (&lt;0.01)</td>
<td>7 day AM lag</td>
<td>X</td>
</tr>
<tr>
<td>Temperature</td>
<td>2.15 (0.00)</td>
<td>7 day AM lag</td>
<td>1.51 (&lt;0.01)</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>X</td>
<td>_</td>
<td>X</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-2.15 (&lt;0.01)</td>
<td>7 day AM lag</td>
<td>X</td>
</tr>
<tr>
<td>Non-Saturday</td>
<td>48.0 (&lt;0.00)</td>
<td>-</td>
<td>48.3 (0.00)</td>
</tr>
<tr>
<td>Autoregressive Lag effects</td>
<td>-</td>
<td>-</td>
<td>1, 3, 5 (+)</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Wald Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2.313</td>
<td>.0759</td>
<td>2.164</td>
<td>2.462</td>
<td>928.828</td>
<td>1</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.247</td>
<td>.0536</td>
<td>.142</td>
<td>.352</td>
<td>21.290</td>
<td>1</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>[Autumn=No]</td>
<td>-.0897</td>
<td>.0436</td>
<td>-.175</td>
<td>-.004</td>
<td>4.237</td>
<td>1</td>
</tr>
<tr>
<td>[Autumn=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>[Winter=No]</td>
<td>-.1186</td>
<td>.0472</td>
<td>-.211</td>
<td>-.026</td>
<td>6.323</td>
<td>1</td>
</tr>
<tr>
<td>[Winter=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>NO2_7 (AM)</td>
<td>-.7351</td>
<td>.1455</td>
<td>-1.020</td>
<td>-.450</td>
<td>25.544</td>
<td>1</td>
</tr>
</tbody>
</table>

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 NO2 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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_2$(AM)</td>
<td>-0.7351</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>0.479</td>
<td>-52.05</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.247</td>
<td>1</td>
<td>-</td>
<td>1.280</td>
<td>28.02</td>
</tr>
<tr>
<td>Not Autumn*</td>
<td>-0.0897</td>
<td>1</td>
<td>-</td>
<td>0.914</td>
<td>-8.58</td>
</tr>
<tr>
<td>Not Winter*</td>
<td>-0.1186</td>
<td>1</td>
<td>-</td>
<td>0.888</td>
<td>-11.18</td>
</tr>
</tbody>
</table>

*Categorical variable

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

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta$</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>1.814</td>
<td>.1020</td>
<td>1.614</td>
<td>2.014</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.283</td>
<td>.0540</td>
<td>.177</td>
<td>.389</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0</td>
<td></td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>[Winter=No]</td>
<td>-.0757</td>
<td>.0467</td>
<td>-.167</td>
<td>.016</td>
</tr>
<tr>
<td>[Winter=Yes]</td>
<td>0</td>
<td></td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>NO$_2$ (AM)</td>
<td>-.597</td>
<td>.1404</td>
<td>-.872</td>
<td>-.322</td>
</tr>
<tr>
<td>Respiratory$_1$</td>
<td>.0219</td>
<td>.0043</td>
<td>.013</td>
<td>.030</td>
</tr>
<tr>
<td>Respiratory$_5$</td>
<td>.0139</td>
<td>.0044</td>
<td>.005</td>
<td>.023</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_2$ (AM)</td>
<td>-0.5970</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>0.550</td>
<td>-44.95</td>
</tr>
<tr>
<td>Non-Saturday$^*$</td>
<td>0.283</td>
<td>1</td>
<td>-</td>
<td>1.327</td>
<td>32.71</td>
</tr>
<tr>
<td>Not Winter$^*$</td>
<td>-0.0757</td>
<td>1</td>
<td>-</td>
<td>0.927</td>
<td>-7.29</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=557.2 at 357 df; Residual Deviance:455.2 at 352 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: ( 102 at 5 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;1.5</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No Significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.34; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>One detected but ignored</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta$</th>
<th>Std. Error</th>
<th>Lower</th>
<th>Upper</th>
<th>Wald Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.881</td>
<td>.0887</td>
<td>1.708</td>
<td>2.055</td>
<td>450.289</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.321</td>
<td>.0666</td>
<td>.191</td>
<td>.452</td>
<td>23.291</td>
<td>1</td>
<td>.000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td>.</td>
</tr>
<tr>
<td>[Autumn=No]</td>
<td>-.150</td>
<td>.0634</td>
<td>-.274</td>
<td>-.025</td>
<td>5.579</td>
<td>1</td>
<td>.018</td>
</tr>
<tr>
<td>[Autumn=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td>.</td>
</tr>
<tr>
<td>Rainfall_7 (AM)</td>
<td>-.0106</td>
<td>.0061</td>
<td>-.023</td>
<td>.001</td>
<td>3.001</td>
<td>1</td>
<td>.083</td>
</tr>
<tr>
<td>NO$_2$ _7 (Mean)</td>
<td>-.8522</td>
<td>.1707</td>
<td>-1.187</td>
<td>-.518</td>
<td>24.934</td>
<td>1</td>
<td>.000</td>
</tr>
</tbody>
</table>

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 NO₂ 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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂_7 (mean)</td>
<td>-0.8522</td>
<td>1</td>
<td>mg/m³</td>
<td>0.426</td>
<td>-57.35</td>
</tr>
<tr>
<td>Rainfall_7 (AM)</td>
<td>-0.0106</td>
<td></td>
<td>mm</td>
<td>0.989</td>
<td>-1.05</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.321</td>
<td>1</td>
<td></td>
<td>1.379</td>
<td>37.85</td>
</tr>
<tr>
<td>Not Autumn*</td>
<td>-0.15</td>
<td>1</td>
<td></td>
<td>0.861</td>
<td>-13.93</td>
</tr>
</tbody>
</table>

*Categorical variable

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

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

<table>
<thead>
<tr>
<th>Parameter Estimate</th>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td></td>
<td>1.478</td>
<td>.1193</td>
<td>1.244</td>
<td>1.712</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td></td>
<td>.361</td>
<td>.0670</td>
<td>.229</td>
<td>.492</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td></td>
<td>0</td>
<td></td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>[Autumn=No]</td>
<td></td>
<td>-.104</td>
<td>.0649</td>
<td>-.231</td>
<td>.023</td>
</tr>
<tr>
<td>[Autumn=Yes]</td>
<td></td>
<td>0</td>
<td></td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>NO₂_7 (Mean)</td>
<td></td>
<td>-.6602</td>
<td>.1747</td>
<td>-1.003</td>
<td>-.318</td>
</tr>
<tr>
<td>Rainfall_7(AM)</td>
<td></td>
<td>-.0097</td>
<td>.0062</td>
<td>-.022</td>
<td>.002</td>
</tr>
<tr>
<td>Respiratory_1</td>
<td></td>
<td>.0234</td>
<td>.0064</td>
<td>.011</td>
<td>.036</td>
</tr>
<tr>
<td>Respiratory_5</td>
<td></td>
<td>.0215</td>
<td>.0065</td>
<td>.009</td>
<td>.034</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂_7 (mean)</td>
<td>-0.6602</td>
<td>1</td>
<td>mg/m³</td>
<td>0.517</td>
<td>-48.33</td>
</tr>
<tr>
<td>Rainfall_7 (AM)</td>
<td>-0.0097</td>
<td>1</td>
<td>mm</td>
<td>0.990</td>
<td>-0.97</td>
</tr>
<tr>
<td>Non-Saturdays</td>
<td>0.361</td>
<td>1</td>
<td>-</td>
<td>1.435</td>
<td>43.48</td>
</tr>
<tr>
<td>Not Autumn</td>
<td>-0.104</td>
<td>1</td>
<td>-</td>
<td>0.901</td>
<td>-9.88</td>
</tr>
</tbody>
</table>

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

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

![Pearson Residual Diagram](image.png)

![ACF Diagram](image.png)
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Respiratory (Autoregressive)</th>
<th>Respiratory KTM</th>
<th>Respiratory KTM (Autoregressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CO</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>-52.05 (0.00)</td>
<td>-44.95 (0.00)</td>
<td>-57.35 (0.00)</td>
</tr>
<tr>
<td>Not Spring</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Not Autumn</td>
<td>-8.58 (0.04)</td>
<td>-13.93 (&lt;0.02)</td>
<td>-9.88 (0.01)</td>
</tr>
<tr>
<td>Not Winter</td>
<td>-11.2 (&lt;0.01)</td>
<td>-7.29 (0.01)</td>
<td>X</td>
</tr>
<tr>
<td>Rainfall</td>
<td>X</td>
<td>X</td>
<td>-1.05 (0.08)</td>
</tr>
<tr>
<td>Non-Saturday</td>
<td>28.0 (0.00)</td>
<td>32.7 (0.00)</td>
<td>37.9 (0.00)</td>
</tr>
<tr>
<td>Autoregressive lag effects</td>
<td>-</td>
<td>-</td>
<td>1, 5 (+)</td>
</tr>
</tbody>
</table>

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.

| Parameter            | β    | Std. Error | 95% Wald Confidence Interval | Hypothesis Test | Parameter Estimates         |
|----------------------|------|------------|------------------------------|----------------|
| (Intercept)          | 3.670| .1391      | 3.398 3.943                  | 696.029 1      | 95% Wald Confidence Interval |
| [Saturday=No]        | .415 | .0426      | .331 .498                    | 94.993 1      | Sig.                        |
| [Saturday=Yes]       | 0a   | . . .       | . . .                        | . . .          |                             |
| PM_0                 | .0012| .0005      | .000 002                     | 7.055 1       | .008                        |
| NO2_2 (Mean)         | .0917| .0548      | -.016 .199                   | 2.801 1       | .094                        |
| Relative Humidity_2 (Mean) | -.0295| .0030 | -.035 -.024                  | 93.641 1    |
| Rainfall_2 (Mean)    | -.0060| .0026 | -.011 -.001                  | 5.391 1     |

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>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ 0</td>
<td>0.0012</td>
<td>10 µg/m$^3$</td>
<td>1.012</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ 2 (mean)</td>
<td>0.0917</td>
<td>1 mg/m$^3$</td>
<td>1.096</td>
<td>9.60</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity_2 (Mean)</td>
<td>-0.0295</td>
<td>1 %</td>
<td>0.971</td>
<td>-2.91</td>
<td></td>
</tr>
<tr>
<td>Rainfall_2 (Mean)</td>
<td>-0.006</td>
<td>1 mm</td>
<td>0.994</td>
<td>-0.60</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.415</td>
<td>1</td>
<td>1.514</td>
<td>51.44</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;2</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Slight significant autocorrelations at 1 and 2 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.46; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>One detected but ignored</td>
</tr>
</tbody>
</table>

![Graph showing standardized Pearson residual vs. predicted value of mean of response](image)
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2.722</td>
<td>.1743</td>
<td>2.381 to 3.064</td>
<td>244.059, 1, .000</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.422</td>
<td>.0426</td>
<td>.339 to .506</td>
<td>98.344, 1, .000</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM_0</td>
<td>.0008</td>
<td>.0005</td>
<td>-8.23E-005 to .002</td>
<td>3.179, 1, .075</td>
</tr>
<tr>
<td>NO2_2 (Mean)</td>
<td>.0723</td>
<td>.0545</td>
<td>-.034 to .179</td>
<td>1.761, 1, .184</td>
</tr>
<tr>
<td>Relative Humidity_2 (Mean)</td>
<td>-.0164</td>
<td>.0034</td>
<td>-.023 to -.010</td>
<td>23.487, 1, .000</td>
</tr>
<tr>
<td>Rainfall_2 (Mean)</td>
<td>-.0041</td>
<td>.0026</td>
<td>-.009 to .001</td>
<td>2.459, 1, .117</td>
</tr>
<tr>
<td>Respiratory_1</td>
<td>.0090</td>
<td>.0019</td>
<td>.005 to .013</td>
<td>22.431, 1, .000</td>
</tr>
<tr>
<td>Respiratory_2</td>
<td>.0135</td>
<td>.0019</td>
<td>.010 to .017</td>
<td>49.120, 1, .000</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$ _0</td>
<td>0.0008</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.008</td>
<td>0.80</td>
</tr>
<tr>
<td>NO$_2$ _2 (mean)</td>
<td>0.0723</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>1.075</td>
<td>7.50</td>
</tr>
<tr>
<td>Relative Humidity _2 (Mean)</td>
<td>-0.0164</td>
<td>1</td>
<td>%</td>
<td>0.984</td>
<td>-1.63</td>
</tr>
<tr>
<td>Rainfall _2 (Mean)</td>
<td>-0.0041</td>
<td>1</td>
<td>mm</td>
<td>0.996</td>
<td>-0.41</td>
</tr>
<tr>
<td>Non-Saturdays$^*$</td>
<td>0.422</td>
<td>1</td>
<td>-</td>
<td>1.525</td>
<td>52.50</td>
</tr>
</tbody>
</table>

*Categorical variable

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;1.5</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Just significant autocorrelation at 7 lag (ignored)</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.48; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>One detected but ignored</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.098</td>
<td>.2442</td>
<td>2.620 3.577</td>
<td>160.956 1 .000</td>
</tr>
<tr>
<td>[Monday=No]</td>
<td>.383</td>
<td>.0526</td>
<td>.280  .486</td>
<td>52.917 1 .000</td>
</tr>
<tr>
<td>[Monday=Yes]</td>
<td>0a</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM2.5_0</td>
<td>.0029</td>
<td>.0007</td>
<td>.001  .004</td>
<td>15.914 1 .000</td>
</tr>
<tr>
<td>CO_0</td>
<td>.0571</td>
<td>.0308</td>
<td>-.003   .117</td>
<td>3.450 1 .063</td>
</tr>
<tr>
<td>Temperature_0</td>
<td>.0073</td>
<td>.0041</td>
<td>-.001   .015</td>
<td>3.182 1 .074</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0314</td>
<td>.0039</td>
<td>-.039   -.024</td>
<td>65.102 1 .000</td>
</tr>
<tr>
<td>Rainfall_2 (Mean)</td>
<td>-.0064</td>
<td>.0033</td>
<td>-.013   -1.463E-005</td>
<td>3.859 1 .049</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$-0</td>
<td>0.0029</td>
<td>10 µg/m$^3$</td>
<td>1.029</td>
<td>2.94</td>
<td></td>
</tr>
<tr>
<td>CO_0</td>
<td>0.0571</td>
<td>1 mg/m$^3$</td>
<td>1.059</td>
<td>5.88</td>
<td></td>
</tr>
<tr>
<td>Temperature_0</td>
<td>0.0073</td>
<td>1 %</td>
<td>1.007</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-0.0314</td>
<td>1 %</td>
<td>0.969</td>
<td>-3.09</td>
<td></td>
</tr>
<tr>
<td>Rainfall_2 (Mean)</td>
<td>-0.0064</td>
<td>1 mm</td>
<td>0.994</td>
<td>-0.64</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.383</td>
<td>1</td>
<td>1.467</td>
<td>46.67</td>
<td></td>
</tr>
</tbody>
</table>

*Categorical variable
### Table 107: Aged respiratory effect model (address Kathmandu valley): Model adequacy test

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>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 &lt;0.0001)</td>
<td>Good</td>
</tr>
<tr>
<td>Multicollinearity-</td>
<td>VIFs&lt;2.6</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>Slightly significant autocorrelation at 1 and 2 lags</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.45; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>One detected but ignored</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Estimates</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td></td>
<td>Lower</td>
<td>Upper</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>2.644</td>
<td>.2105</td>
<td>2.232</td>
<td>3.057</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.377</td>
<td>.0526</td>
<td>.274</td>
<td>.480</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0*</td>
<td></td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt; _0</td>
<td>.0018</td>
<td>.0005</td>
<td>.001</td>
<td>.003</td>
</tr>
<tr>
<td>CO _0</td>
<td>.0567</td>
<td>.0309</td>
<td>-.004</td>
<td>.117</td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-.0232</td>
<td>.0041</td>
<td>-.031</td>
<td>-.015</td>
</tr>
<tr>
<td>Respiratory_1</td>
<td>.0097</td>
<td>.0033</td>
<td>.003</td>
<td>.016</td>
</tr>
<tr>
<td>Respiratory_2</td>
<td>.0163</td>
<td>.0033</td>
<td>.010</td>
<td>.023</td>
</tr>
</tbody>
</table>

* 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<sub>2.5</sub> (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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt; _0</td>
<td>0.0018</td>
<td>10 µg/m³</td>
<td>1.018</td>
<td>1.82</td>
<td></td>
</tr>
<tr>
<td>CO _0</td>
<td>0.0567</td>
<td>1 mg/m³</td>
<td>1.058</td>
<td>5.83</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity_0</td>
<td>-0.0232</td>
<td>1 %</td>
<td>0.977</td>
<td>-2.29</td>
<td></td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.377</td>
<td>1</td>
<td>1.458</td>
<td>45.79</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=814.4 at 362 df; Residual Deviance:568 at 356 df</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Omnibus test: highly significant with log likelihood chi-square: ( 246.4 at 6 df; p &lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIfs&lt;1.4</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Constant variance</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.31; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatter plots between residuals versus mean predicted values</td>
<td>Few detected but ignored</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Respiratory (Autoregressive)</th>
<th>Respiratory KTM</th>
<th>Respiratory KTM (Autoregressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% lag</td>
<td>% lag</td>
<td>% lag</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>1.21 (0.01)</td>
<td>2.94 (0.00)</td>
<td>1.82 (0.0)</td>
</tr>
<tr>
<td></td>
<td>0 (0.08)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO</td>
<td>X</td>
<td>5.88 (0.06)</td>
<td>5.83 (0.07)</td>
</tr>
<tr>
<td></td>
<td>0.80 (0.08)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>9.6 (0.09)</td>
<td>2 day mean</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>0.73 (0.07)</td>
<td>X</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>X</td>
<td>-2.91 (0.00)</td>
<td>-2.99 (0.00)</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.6 (0.02)</td>
<td>2 day mean</td>
<td>X</td>
</tr>
<tr>
<td>Non-Saturday</td>
<td>51.4 (0.00)</td>
<td>46.7 (0.00)</td>
<td>45.8 (0.00)</td>
</tr>
<tr>
<td></td>
<td>Autoregressive lag effects</td>
<td>1, 2 (+)</td>
<td>1, 2 (+)</td>
</tr>
</tbody>
</table>

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$^\circ$ 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>B</th>
<th>Std. Error</th>
<th>95% Wald Confidence Interval</th>
<th>Hypothesis Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>.450</td>
<td>.2521</td>
<td>-.044 to .944</td>
<td>3.183, 1 df, .074</td>
</tr>
<tr>
<td>[Saturday=No]</td>
<td>.261</td>
<td>.0950</td>
<td>.075 to .447</td>
<td>7.532, 1 df, .006</td>
</tr>
<tr>
<td>[Saturday=Yes]</td>
<td>0.0</td>
<td>.</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5\text{ (Geo)}}$</td>
<td>.0036</td>
<td>.0016</td>
<td>.000 to .007</td>
<td>5.199, 1 df, .023</td>
</tr>
<tr>
<td>CO$_0$</td>
<td>.1402</td>
<td>.0478</td>
<td>.047 to .234</td>
<td>8.606, 1 df, .003</td>
</tr>
<tr>
<td>NO$_2\text{ (Geo)}$</td>
<td>-.406</td>
<td>.2245</td>
<td>-.846 to .035</td>
<td>3.262, 1 df, .071</td>
</tr>
<tr>
<td>Temperature$_0$</td>
<td>.014</td>
<td>.0078</td>
<td>-.001 to .029</td>
<td>3.170, 1 df, .075</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Increase</th>
<th>Unit</th>
<th>RR</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5\text{ (Geo)}}$</td>
<td>0.0036</td>
<td>10</td>
<td>µg/m$^3$</td>
<td>1.037</td>
<td>3.67</td>
</tr>
<tr>
<td>CO$_0$</td>
<td>0.1402</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>1.151</td>
<td>15.05</td>
</tr>
<tr>
<td>NO$_2\text{ (Geo)}$</td>
<td>-0.406</td>
<td>1</td>
<td>mg/m$^3$</td>
<td>0.666</td>
<td>-33.37</td>
</tr>
<tr>
<td>Temperature$_0$</td>
<td>0.014</td>
<td>1</td>
<td>°C</td>
<td>1.014</td>
<td>1.41</td>
</tr>
<tr>
<td>Non-Saturdays*</td>
<td>0.261</td>
<td>1</td>
<td></td>
<td>1.298</td>
<td>29.82</td>
</tr>
</tbody>
</table>

*Categorical variable
3.3.7.1 Model adequacy test.

Table 114: Mortality effect model: Model adequacy test

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goodness of fit</td>
<td>Null Deviance=620.5 at 357 df; Residual Deviance:596.8 at 352 df</td>
<td>Good</td>
</tr>
<tr>
<td>Omnibus test: highly significant with log likelihood chi-square: (23.65 at 5 df; p &lt;0.0001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multicollinearity</td>
<td>VIFs&lt;2.6</td>
<td>No multicollinearity</td>
</tr>
<tr>
<td>Heteroscedasticity</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Constant variance (ignoring three highest mean predicted observations)</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>Correlogram (up to lag 7)</td>
<td>No significant autocorrelations</td>
</tr>
<tr>
<td>Normality</td>
<td>KS test for deviance residual with p =0.2; normal q-q plot</td>
<td>Deviance residual normal (preferred)</td>
</tr>
<tr>
<td>Outlier</td>
<td>Scatterplots between residuals versus mean predicted values</td>
<td>Few detected but ignored</td>
</tr>
</tbody>
</table>
Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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:

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

$RR_i$ = 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>
<thead>
<tr>
<th>PM$_{2.5}$ Level</th>
<th>Frequency (Days)</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>102</td>
<td>27.9</td>
<td>27.9</td>
</tr>
<tr>
<td>20-40</td>
<td>56</td>
<td>15.3</td>
<td>43.3</td>
</tr>
<tr>
<td>40-60</td>
<td>72</td>
<td>19.7</td>
<td>63.0</td>
</tr>
<tr>
<td>60-80</td>
<td>75</td>
<td>20.5</td>
<td>83.6</td>
</tr>
<tr>
<td>80-100</td>
<td>32</td>
<td>8.8</td>
<td>92.3</td>
</tr>
<tr>
<td>100-120</td>
<td>17</td>
<td>4.7</td>
<td>97.0</td>
</tr>
<tr>
<td>120-140</td>
<td>8</td>
<td>2.2</td>
<td>99.2</td>
</tr>
<tr>
<td>140-160</td>
<td>1</td>
<td>0.3</td>
<td>99.5</td>
</tr>
<tr>
<td>160-180</td>
<td>1</td>
<td>0.3</td>
<td>99.7</td>
</tr>
<tr>
<td>180-200</td>
<td>1</td>
<td>0.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>365</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Disease</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumonia</td>
<td>12839</td>
</tr>
<tr>
<td>COPD</td>
<td>19847</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>11139</td>
</tr>
<tr>
<td>Asthma</td>
<td>21671</td>
</tr>
<tr>
<td>ARI</td>
<td>78249</td>
</tr>
<tr>
<td>Otitis Media</td>
<td>17043</td>
</tr>
<tr>
<td>Sinusitis</td>
<td>29157</td>
</tr>
<tr>
<td>Tonsillitis</td>
<td>14459</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>228</td>
</tr>
<tr>
<td>TB</td>
<td>5046</td>
</tr>
<tr>
<td>Total</td>
<td>222517</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Disease Burden</th>
<th>AF</th>
<th>Total Burden (Inpatients)</th>
<th>Attributable Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>0.0483</td>
<td>11321</td>
<td>547</td>
</tr>
<tr>
<td>COPD</td>
<td>0.0625</td>
<td>4463</td>
<td>279</td>
</tr>
<tr>
<td>ARI</td>
<td>0.0953</td>
<td>5025</td>
<td>479</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>0.1545</td>
<td>3292</td>
<td>509</td>
</tr>
<tr>
<td>Respiratory (Aged≥50)</td>
<td>0.0860</td>
<td>6207</td>
<td>534</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Disease</th>
<th>AF</th>
<th>Total Morbidity</th>
<th>Attributable Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>0.0483</td>
<td>222517</td>
<td>10748</td>
</tr>
<tr>
<td>COPD</td>
<td>0.0625</td>
<td>19847</td>
<td>1240</td>
</tr>
<tr>
<td>ARI</td>
<td>0.0953</td>
<td>78249</td>
<td>7457</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>0.1545</td>
<td>12839</td>
<td>1984</td>
</tr>
</tbody>
</table>

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 NO₂

The attributable fractions and burdens of diseases that can be attributed to ambient NO₂ 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 μg/m³ is accepted for EBD assessment.
Table 119: NO$_2$ level assessment

<table>
<thead>
<tr>
<th>NO$_2$ Level</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-80</td>
<td>159</td>
<td>43.6</td>
<td>43.6</td>
</tr>
<tr>
<td>80-100</td>
<td>16</td>
<td>4.4</td>
<td>47.9</td>
</tr>
<tr>
<td>100-150</td>
<td>38</td>
<td>10.4</td>
<td>58.4</td>
</tr>
<tr>
<td>150-200</td>
<td>37</td>
<td>10.1</td>
<td>68.5</td>
</tr>
<tr>
<td>200-250</td>
<td>41</td>
<td>11.2</td>
<td>79.7</td>
</tr>
<tr>
<td>250-300</td>
<td>15</td>
<td>4.1</td>
<td>83.8</td>
</tr>
<tr>
<td>300-350</td>
<td>17</td>
<td>4.7</td>
<td>88.5</td>
</tr>
<tr>
<td>350-450</td>
<td>10</td>
<td>2.7</td>
<td>91.2</td>
</tr>
<tr>
<td>450-550</td>
<td>10</td>
<td>2.7</td>
<td>94.0</td>
</tr>
<tr>
<td>550-700</td>
<td>10</td>
<td>2.7</td>
<td>96.7</td>
</tr>
<tr>
<td>700-1000</td>
<td>8</td>
<td>2.2</td>
<td>98.9</td>
</tr>
<tr>
<td>1000-3500</td>
<td>4</td>
<td>1.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>365</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 120: Burden of diseases attributed to ambient NO$_2$

<table>
<thead>
<tr>
<th>Disease Burden</th>
<th>AF</th>
<th>DoHs</th>
<th>Total Burden (Inpatients)</th>
<th>Attributable Burden (DoHs Morbidity)</th>
<th>Attributable Burden (Inpatients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPD</td>
<td>0.0534</td>
<td>19847</td>
<td>4463</td>
<td>1060</td>
<td>238</td>
</tr>
<tr>
<td>Respiratory</td>
<td>0.0162</td>
<td>-</td>
<td>6207</td>
<td>-</td>
<td>101</td>
</tr>
<tr>
<td>(Aged≥50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Burden of diseases attributed to ambient NO$_2$ which is higher in COPD (0.0534) in compared with Respiratory Aged≥50 (0.0162)
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 cities 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 micro-
environmental 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 NO₂ ambient air pollution, cold winter months were relatively more polluted than hot and wet months, similar to the situation for PM₂.₅ 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 PM₂.₅, CO and NO₂ from March 2013 to March 2014 also showed changes from rainy to dry seasons for PM₂.₅, CO, and NOₓ of 49-73 µg/m³ (40%), 2.5-3.8 ppm (40%), and 144-252 ppb (53%), respectively (21).

PM₂.₅, hourly levels are at their lowest (below 40 µg/m³) during the post-midnight until pre-dawn period (0-5 AM). They gradually increase throughout the morning and attain their highest level (87 µg/m³) during 8-9 AM. Levels then decrease to their lowest value (31 µg/m³) during the afternoon (2-3 PM). Thereafter, levels increase again, reaching a peak (59 µg/m³) at 8-9 PM before gradually decreasing late at night. Hourly NO₂ averages show cyclical variation similar to PM₂.₅ hourly variation. The averages are consistently much higher than the 24-hour standard of 80 µg/m³, which reveals that Kathmandu Valley is highly polluted with ambient NO₂ pollution. Relatively, levels are on the lower side in the period after midnight until pre-dawn (160-170 µg/m³) and start rising in the early morning (5-6 AM). Levels rise to around 270 µg/m³ by 9-10 AM and decrease gradually during the daytime to reach around 140 µg/m³ by 4-6 PM. The levels then again rise, to around 180 µg/m³, at 6-9 PM, then decrease through until midnight (150 µg/m³). 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, PM₂.₅ 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 PM₂.₅ and NO₂ (21). In Nepal, hourly averages of CO are very low from midnight until pre-dawn (less than 200 µg/m³) and start to increase from early morning (5-6 AM), reaching around 635 µg/m³ by 10-11 AM. The level remains relatively high throughout daytime until 2-3 PM (500-670 µg/m³), then dips to around 400 µg/m³ during 4-5 PM. The level then again increases to a maximum of around 725 µg/m³ at 7-8 PM, and decreases thereafter through midnight (189 µg/m³) till the pre-dawn period (118 µg/m³). However, despite this variation, values remain well below the 8 hour NAAQS of 10000 µg/m³ 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 PM₂.₅ and NO₂, 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 temperature, rainfall and humidity, 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°C 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°C 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).
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/m³); a slight decrease in Aswin 2071 (78.4 µg/m³) and Poush 2071 (85.5 µg/m³) was also seen. This demonstrates that warmer months are relatively less polluted with PM<sub>2.5</sub> 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<sub>2.5</sub> levels and weather parameters. There was a cyclic variation in monthly average of CO as it rose from Falgun 2070 (384.9 µg/m³) to Baishak 2071 (576.6 µg/m³); decreased in Jesta 2071 (208.8 µg/m³) and again increased until Shrawan 2071 (742.6 µg/m³). It then decreased until Aswin (151.4 µg/m³), increased until Poush 2071 (626.5 µg/m³) and then decreased in Magh 2071 (424.9 µg/m³). The correlation matrix shows that no statistically significant association exists between CO and any meteorological parameters. Monthly NO<sub>2</sub> levels were low from Shrawan (32 µg/m³) to Kartik (70.9 µg/m³), very high from Magh to Falgun and Baishak (around 350-530 µg/m³), and high for the remaining months (above 90 µg/m³). On average, winter and dry months (the highest in Magh) had higher NO<sub>2</sub> levels compared to warm and wet months. The negative link between NO<sub>2</sub> 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<sub>2.5</sub> pattern**
Observing the PM<sub>2.5</sub> variation, it is found that the level was the lowest (below 40 µg/m³) during post-midnight and before dawn (0-5 AM). It gradually increases throughout the morning and reaches a peak (87 µg/m³) from 8-9 AM. Thereafter, it gradually decreases to its lowest value (31 µg/m³) during the afternoon (2-3 PM). The level then increases again and attains a second peak (59 µg/m³) 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/m³) and start to increase during the early morning (5-6 AM), reaching around 635 µg/m³ by 10-11 AM. The level remains relatively high throughout the day until 2-3 PM (500-670 µg/m³) and decreases slightly to around 400 µg/m³ by 4-5 PM. The level again increases to around 725 µg/m³ by 7-8 PM, and decreases thereafter through midnight (189 µg/m³) until the before-dawn...
period (118 µg/m³). 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/m³.

**NO₂ pattern**

Hourly NO₂ averages show cyclical variation similar to PM₂.₅. The averages are consistently much higher than the 24-hour standard of 80 µg/m³, which reveals that Kathmandu Valley is highly polluted with ambient NO₂. Relatively, the level is on the lower side after midnight and in the before-dawn period (160-170 µg/m³), and starts rising in the early morning (5-6 AM). The level rises to around 270 µg/m³ by 9-10 AM and decreases gradually throughout the day to around 140 µg/m³ by 4-6 PM. The level then again rises to around 180 µg/m³ by 6-9 PM before decreasing though till midnight (150 µg/m³).

PM₂.₅ 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 PM₂.₅ pollution in ambient air was 1.33 times higher during load shedding. The higher levels of PM₂.₅ 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 PM₂.₅ levels during power outage. The ratio of PM₂.₅ 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, heteroscedasticity, 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/m³ 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°C 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/m³ 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/m³ 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/m³ 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 µg/m³ 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/m$^3$ 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/m$^3$ 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/m$^3$ 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/m$^3$ rise in PM2.5 (7 day geometric lag effect), CO was associated with 0.15% rise in mortality per 10 µg/m$^3$ 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, heteroscedasticity, 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. Heteroscedasticity as assessed by residual plots of standardized Pearson and deviance residuals versus predicted values demonstrated fairly 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.
REFERENCES

3. World Health Organization. GLOBAL HEALTH RISKS GLOBAL HEALTH RISKS, Mortality and burden of disease attributable to selected major risks 2015.
5. World Health Organization. Outdoor air pollution: assessing the environmental burden of disease at national and local levels 2015.
Data Collection Sheet

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

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Photos of monitoring stations and instruments

Putalishadak, Kathmandu

Mahalaxmisthan, Lalitpur

CO and NO₂ measurement instruments

Bhimsensthan, Bhaktpur
## Data Tables

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

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

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Table A3: PM$_{2.5}$ scenario of Kathmandu Valley (for all three stations): Between-stations monthly variation
### Table A4: CO scenario of Kathmandu Valley (for all three stations): Between-stations monthly variation

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

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

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### Table A8: NO₂ assessment of 3-hourly intervals between stations

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Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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**Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015**

199
### Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

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Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
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### Table A14: CO assessment of hourly intervals for all stations

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Table A15: CO between-stations hourly levels
### Table A16: NO₂ hourly levels for all stations

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### Table A17: NO₂ between-stations hourly levels

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<th>Bhaktapur Mean</th>
<th>N</th>
<th>SD</th>
<th>Lalitpur Mean</th>
<th>N</th>
<th>SD</th>
</tr>
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<td>191.2</td>
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Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015
### Table A18: Between-station CO variation

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

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

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

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</tr>
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</tr>
<tr>
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<td>1207</td>
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Situation Analysis of Ambient Air Pollution and Respiratory Health Effects in Kathmandu Valley, 2015

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