HEALTH EFFECTS
OF SHORT
AND LONG-TERM
AIR POLLUTION
EXPOSURE

CLIMATE TRENDS
Indian Institute of Technology Delhi
CERCA

FOREWORD

Air pollution is a global crisis which deserves sustained attention to find long-term solutions. Joining up action which brings a good quality of life to citizens, improves public health and addresses pollution management is our only chance to ensure sustainable development.

In 2019, the Indian government launched the National Clean Air Programme (NCAP), encompassing over 130 cities, making India the only South Asian country with a nationwide air pollution management policy. Yet, the devastating health impacts of air pollution remain widely unaddressed in India and across the world.

The NCAP's focus on cities also leaves out the rural population from its scope of action. Air quality monitoring is carried out at only 27 rural locations by the manual method, covering 26 villages in Punjab and one in Daman and Diu, and Dadra and Nagar Haveli. With little monitoring, there isn't enough evidence to draw conclusions about the impact of air pollution on the health of the rural folk. It is, however, widely understood that most of the rural population continues to use biomass bio-fuels for cooking and exposes themselves to high levels of indoor air pollution.

For years, several international studies have established a correlation between high levels of air pollution and higher incidence of several health impacts. But evidence from India is still limited. But as air quality monitoring is strengthened and mitigation measures are put in place, there is a simultaneous need to create national public health data that should allow for science-based decision making.

Climate Trends is grateful to the authors of the study for the collaboration and for building a strong case for policy-level action to control air pollution in both urban and rural areas of the country.

This report specifically looks at a set of regions in the state of West Bengal and brings out the adverse respiratory impacts of air pollution across these areas, which span rural and urban parts of the state. Through detailed interviews with over 1,100 people, this study correlates the health impacts reflected in symptoms, to the different levels of air pollution exposure. Evidently, while urban areas have more severe impacts due to long-term exposure to poor air, women and the elderly in rural areas suffer as much as they are exposed to indoor air pollution as well. The study shows that indoor air pollution is a key component of adverse health outcomes in rural settings.

In the last few years, we have witnessed such destruction of air quality that air pollution has been climbing up, ironically, to become the leading cause of death ahead of chronic diseases like high cholesterol, diabetes and obesity. It is also impacting the most vulnerable. Nearly 20 percent of newborn deaths each year are due to air pollution, and significant numbers are from Asia and Africa.

The air pollution crisis has been a long time in the making. The tipping point has crossed. There is an urgent need for more ambition and action to integrate health into clean air policies; and focus on an airshed strategy for the region to encompass both urban and rural pockets. Research must be used to bring health to the forefront in India's fight against air pollution. Health organisations or government bodies must be engaged to include health in the planning stage of air pollution reduction policies.

It is finally the improvement in human health which will be the true success matrix of all air pollution mitigation efforts.

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ABBREVIATIONS

CI: Confidence Interval (95%)
COPD: Chronic Obstructive Pulmonary Disease
CPCB: Central Pollution Control Board
CV: Cross Validation
DALY: Disability-Adjusted Life Years
EF: Emission Factors
GBD: Global Burden of Disease
GHSL: Global Human Settlement Layers
LRI: Lower Respiratory Infection
LRS: Lower Respiratory Symptoms
MW: Mega-Watt
NAAQS: National Ambient Air Quality Standards
OR: Odds Ratio
$PM_{2.5}$: Particulate Matter of diameter of <2.5 µm
RMSE: Root Mean Square Error
RR: Relative Risk
R^2 : Coefficient of Determination
SES: Socio-Economic Status
SHS: Second-hand Tobacco Smoking
T2DM: Type-2 Diabetes Mellitus
TB: Tuberculosis
URS: Upper Respiratory Symptoms
WHO: World Health Organization

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AUTHORS' CONTRIBUTIONS

Dr. Manas Ranjan Ray designed the study. Dr. Palak Balyan developed the questionnaire and Prof. Sagnik Dey provided the $PM_{2.5}$ data. Debajit Sarkar, Tanya Gupta, Aritra Jana, Raya Majumdar, Swatilekha Ghosh, Debolina Banerjee, Esha Chatterjee, Anindita Roy, Susmita Mann, Mukulika Roy, Rohit Chakroborty, Rishav Sharma, Ambika Nayak, Sumana Dutta and Sohini Mitra conducted the survey. Debajit Sarkar, Alok Kumar, and Tanya Gupta performed the statistical analysis under Dr. Palak Balyan's supervision. Debajit Sarkar and Dr. Palak Balyan drafted the initial report. Dr. Palak Balyan, Dr. Manas Ranjan Ray and Prof. Sagnik Dey revised the report. All authors reviewed the report. The author(s) read and approved the final report.

DECLARATION

The authors declare no conflict of interest.

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EXECUTIVE SUMMARY

Air pollution has been recognized as the world's largest environmental health risk. The Global Burden of Disease (GBD, 2019) declared air pollution as a leading cause of death and disability in India. In 2019, 0.98 million (95% CI: 0.77-1.19) deaths were attributable to ambient $PM_{2.5}$, and 0.61 million (0.39-0.86) deaths were attributable to household $PM_{2.5}$ (Kaur and Pandey, 2021), resulting in an economic loss of 36.8 billion USD (1.36% of India's GDP). These estimates from the Global Burden of Disease (GBD) study allowed a consistent framework that can be applied globally. Worldwide, around 2.8 billion people rely on solid fuels such as wood, dung, coal and crop residue for cooking and space heating. As per the 2011 census, 780 million of them are from India where the residents are mostly rural. In these regions, the concentration of indoor $PM_{2.5}$ is far more than that of ambient air, and it could be responsible for a very high health burden across India (Balakrishnan et al., 2015). While the percentage of the population using solid fuels for cooking has decreased gradually over the years, the absolute numbers remained comparable due to population rise. In simple traditional cookstoves, biomass (wood, dung, crop residue) burning during cooking produces a range of toxic products resulting from incomplete combustion, including $PM_{2.5}$ which is roughly equal to burning about 400 cigarettes an hour. Given that this occurs in closed places with little ventilation, a large percentage of the population (particularly women and children who tend to be in the kitchen most) are exposed to this source of pollution.

According to the World Health Organization's (WHO) Ambient Air Pollution database of 2019, 21 of the top 30 cities in the world with the highest annual levels of $PM_{2.5}$ are now in India, with Delhi featuring at the top as the most polluted capital. With relatively weak policies to manage industrial, transport and other emissions, and increasing economic activity and industrialization across the country, the situation is likely to get worse. Along with these, air pollution sources from international contributions (that include dust storms from middle-east and transboundary pollution sources from south-east Asia) are also an added concern for the Indian scenario. In fact, ambient levels of $PM_{2.5}$ from transport sources alone are expected to double by 2030 if no action is taken.

This study aimed to explore the effect of short and long-term exposure to $PM_{2.5}$ on upper and lower respiratory symptoms in the urban and rural population near Kolkata. A total of 1155 people of varying ages were surveyed during 2020-22. We conducted a multivariate regression model to examine the association between air pollution and health outcomes in the overall population, and subgroup stratified by socio-demographic factors, age, gender and lifestyle behavior. We found strong association between health outcomes and long-term exposure in both, rural ($R^2 = 0.89$, $p < 0.01$) and urban ($R^2 = 0.89$, $p < 0.01$) population. For short-term exposure, the model could predict with significant accuracy of 0.8 for rural and 0.74 for urban regions. For every 10 $\mu g/m^3$ increment of $PM_{2.5}$, the highest long and short-term associations in rural people were found in asthma (1.98, CI: 1.24-2.73) and cough (1.47, CI: 1.21-1.73), compared to wheeze (1.45, CI: 1-1.9) and cough (1.54, CI: 1.47-1.61) in urban. For subgroup analysis, the effect of $PM_{2.5}$ exposure was more in males (1.93, CI: 1.85-2) than is females (1.59, CI: 1.47-1.71). The risk was developed in people with low (1.78, CI: 1.57-1.99) and middle (1.53, CI: 1.41-1.65) income category than high SEC in the rural region, whereas people with high (1.82, CI: 1.6-2.02) and middle (1.5, CI: 1.45-1.55) SEC suffered more risk than low SEC in urban regions. In both regions, the aged (1.49, CI: 1.44-1.55) and adults (1.32, CI: 1.25-1.4) were more prone to health risk than the young (1.23, CI: 1.21-1.25) population.

Household emission is a strong source of indoor air pollution in rural regions. Emission source types and duration of exposure influence the association between pollution and health outcomes. Along with these, the types of cooking fuel used, kitchen location, presence of chimney or exhaust in the kitchen and smoking status of the family members proved to be strong determining parameters for health burden development.

While exposure to air pollution is a risk factor common to both rural and urban populations, the routine monitoring of air quality as it stands, is nearly exclusively confined to large cities. This makes the task of understanding the nature and distribution of population exposures much harder. Moreover, studies have shown that emissions from cooking using unprocessed solid biomass contribute to around one-quarter of ambient $PM_{2.5}$ air pollution in the country (Chafe et al., 2014). This serves to highlight that exposure to air pollution, be it ambient or household, is part of a continuum, and reinforces the need for an integrated approach toward mitigation and harm reduction.

KEY FINDINGS

An adult human being takes in about 15,000 liters of air every day and the primary target of all sorts of pollutants inhaled is the lungs and the airways. Prolonged exposure of these pollutants may lead to a host of respiratory diseases that are manifested by some specific upper and lower respiratory symptoms (URS and LRS, respectively). In this study, conducted during 2021 to mid of 2022, we surveyed the prevalence of respiratory and associated symptoms to get an estimate of the adverse lung and systemic reactions to air pollution exposures. In the process, we developed a health database vis-s-vis ambient and indoor air pollution in Kolkata and some parts of West Bengal, through personal interviews using a validated, structured questionnaire.

- In both urban and rural populations, the prevalence of upper respiratory symptoms (URS) including sinusitis, sore throat, runny or stuffy nose and sneezing, was higher than that of lower respiratory symptoms (LRS) that include wet or dry cough, wheeze, labored breathing and chest tightness.

- LRS, which are more serious in nature than URS, were more prevalent among people residing in the urban areas, where the level of air pollution was higher than rural. The respiratory symptoms strongly correlated with $PM_{2.5}$ levels in breathing air.

- In the rural settings, indoor air pollution was found to be a key component of adverse health outcomes. It is evident from our study that rural women developed higher health problems than their male counterparts.

- Indeed, gender plays an important role in susceptibility to air pollution. Both URS and LRS were more prevalent in women than in men. In addition to ambient air pollution, women are also exposed to household (indoor) air pollution as a majority of them participate in daily household cooking. In the process, they get more exposed to the air toxins. This could have contributed to their higher prevalence of respiratory symptoms.

- In the rural areas, people mostly use unprocessed solid biomass fuels (firewood, cow-dung cake, agricultural wastes etc.) for household cooking. Exposure to the pollutants emitted from burning of these fuels for a longer period could cause severe health damage in women, children and the elderly, who spend most of their time indoor. Our finding is consistent with that of Balakrishnan et al. (2015), where household air pollution was found to be an equally important source of exposure compared to ambient air pollution.

- Among the cardiovascular risk factors, hypertension (higher systolic and/or diastolic blood pressure) was most common both in urban and rural settings. Hypertension, that showed positive association with $PM_{2.5}$ levels, is a known risk factor for cardiovascular disease (CVD) including heart attacks and stroke. Globally, up to 80% of all deaths from air pollution are attributed to CVD and the rest to the lung diseases including COPD, lung cancer and childhood pneumonia.

- Like gender, age and socio-economic status (SES) of the people also influenced a person's susceptibility to air pollution. Compared to younger participants within the age of 20 yr, aged (>50 yr) and adults (21-50 yr) showed weak resistance to air pollution exposure, especially for cardiovascular or respiratory systems. Accordingly, adverse health outcomes were more strongly indicated in people of these age-groups.

- Interestingly, urban people belonging to high and low SES suffered more from air pollution exposures than people from medium SES. While the precise reason for these varied responses is yet to be elucidated, the more affected people stayed outdoor for longer periods in the day for their professions. In the process, they get more exposed to ambient air pollutants including $PM_{2.5}$.

- Occupation also emerged as an important determinant of air pollution-related adverse health outcomes. As the transport sector represents an important contributor to outdoor air pollution, especially in urban settings, people with higher exposure to vehicular emissions like drivers of motorized vehicles, traffic policemen, roadside hawkers, gas station workers, motor servicing (garage) workers and students, sales and service personnel, who usually roam around busy thoroughfares, suffered more.

- The duration of outdoor exposure also turned out to be a key factor for health disorders. People with history of prolonged exposure to city's ambient $PM_{2.5}$ suffered more from adverse health conditions.

INTRODUCTION

RATIONALE

As in many other parts of the country, the air pollution levels in cities across West Bengal are higher than the permissible limits set by the Central Pollution Control Board. It has been found in several documentations that prolonged exposure to high level of ambient air pollution adversely affects human health, leading to excess morbidity (illness) and mortality (deaths). Most vulnerable are the women, children and the elderly. Therefore, there is an express need to build a database of the health impacts of air pollution in the state. With this objective, the current project was launched. It aims to generate evidence on the health impacts of air pollution amongst varying segments of the population in West Bengal. This epidemiological study has been conducted across some urban and rural areas which have either been impacted by high levels of air pollution or been protected from such exposure. This evidence will help draw a comparative analysis of the varying health impacts on the population in both categories of areas.

BACKGROUND

Urban areas, which are broadly recognized as towns and cities, are estimated to emit 80% of global CO2 (Ghosh and Maji 2011). The increasing size of the population, with associated anthropogenic activities, has resulted in changes in urban environmental conditions which further create great complexities for urban inhabitants (Kaur and Nagpal, 2017). Air pollution is a major threat to mankind: 9 out of 10 people globally breathe air that is polluted according to World Health Organization (WHO) guideline. Epidemiological studies have shown that air particles are associated with a wide range of health effects, mostly in the cardio-respiratory system (Shen et al., 2018). The World Health Organization (WHO) has estimated that toxic air pollution is responsible for around 8 million people losing their lives every year globally (Harding 2020; WHO report, 2021, reviewed by Max Roser, November 2021).

A joint study by Chittaranjan National Cancer Institute (CNCI), Kolkata, Department of Environment, Government of West Bengal and Central Pollution Control Board has reported that around 70% of people in Kolkata suffer from cardiovascular and respiratory disorders caused by air pollution (Mukhopadhyay, 2009). In 1995, an estimated 10,647 premature deaths were attributed to air pollution in Kolkata (Ghosh, 2002; Schwela et al., 2006). Studies have demonstrated that children inhaling polluted air suffer from adverse lung infections (Lahiri et al., 2000), around 47% of Kolkata's population suffers from lower respiratory infections and the health burden was seven times more than their rural counterparts due to increased air pollution exposure (WBPCB, 2003; Roy et al., 2006). Other air pollution-related health problems, including hematological abnormalities, genetic disorder, impaired liver function and neurological problems were found more prevalent among city hawkers, traffic policemen, auto and taxi drivers. These people are exposed to high level of vehicular emission, and also some also reside near to industries or small to large scale factories (Mukhopadhyay, 2009). A study in 2017 concluded that patients who were admitted in dispensaries were mostly slum dwellers, who had exposure to indoor cooking, lacked the knowledge and had poor resistance to air pollution (Haque and Singh, 2017).

The number of patients admitted in hospitals, dispensaries and health centers has increased in rural regions. Rural regions, broadly understood as villages, suffer from huge dust concentrations, indoor air pollution from cooking bio-fuels and open-field biomass burning. From the analysis of rural settlement data by GHSL, it is clearly seen that the annual $PM_{2.5}$ concentration remains well above the national ambient air quality standards

(NAAQS) set by the CPCB (40 µg/m^3). From our knowledge, few studies have been conducted regarding air pollution health affects in Kolkata and surrounding urban regions. However, no study explores the association between ambient air pollution exposure and health outcomes in rural regions of West Bengal.

AIR POLLUTION SOURCES, CONCENTRATION, AND EXPOSURE

Household Air Pollution (HAP)

Household (or indoor) air pollution from solid cooking fuel use results primarily from incomplete combustion as conditions for efficient combustion of these fuels is difficult to achieve in the typical household stoves. Hundreds of different chemical substances are emitted during the burning of solid biomass in the form of gases and particles. In addition to small particles, carbon monoxide, and nitrogen oxides, which are considered as outdoor pollutants in India, studies have shown that traditional chulhas produce hundreds of other toxic pollutants including formaldehyde, benzene, poly-aromatic hydrocarbons, and even dioxins. 10 Unlike ambient air quality, where national monitoring programs provide at least some level of routine information, exposures to HAP have primarily been characterized by individual research studies, from as far back as the 1980s.

Ambient Air Pollution (AAP)

The rapid growth in the industrial, power, and transportation sectors nationally, teamed with growing planned and unplanned urbanization in India, presents a cause for concern. Residents of urban settlements are exposed to increasingly higher levels of particulate matter (PM^{10} and $PM_{2.5}$), sulphur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO) and ozone. While SO2 levels have declined in recent years, levels of all other pollutants routinely exceed the NAAQS. In over half the cities monitored as part of the National Air Quality Monitoring Programme (NAMP), levels of PM^{10} are critical, and over two-thirds exceed the mandated safe levels of 60 µg/m^3. The NO2 levels have begun to increase in several cities. Although SO2 levels have declined in cities overall, many cities still face unhealthy levels of several pollutants at once. Broadly, though, assessment of source-wise contribution to air pollution is inadequate in India. The CPCB does operate air quality monitoring stations but they are very limited in number and mostly in large cities. Thus, a national picture of the problem can only be derived through satellite modeling. While most of southern India complies with the NAAQS standards, the eastern part of the Indo-Gangetic plain, mostly West Bengal, uniformly registered critical levels of $PM_{2.5}$ attributable to the presence of a large number of brick kilns, old and inefficient combustion technology, and the use of biomass and coal for household cooking and heating needs.

Estimating the health risk

The health risk of air pollution in a population is usually represented by an exposure–response function, which is typically based on Odds Ratio (OR) estimates derived from epidemiological studies. The OR estimate describes the likelihood of an adverse health outcome (e.g. premature death, heart attack, asthma attack, emergency room, i.e. estimating the health risk visit, hospital admission) occurring in a population exposed to a higher level of air pollution relative to that in a population with a lower exposure level. Typically, Relative Risk (RR) is expressed as the proportional increase in the assessed health outcome associated with a given increase in pollutant concentrations in µg per m^3 or parts per billion (ppb) (Katsouyanni, 2003). It is important to note that the OR estimates cannot be assigned to a specific person; it describes risk in a defined population, not individual risk (McAuley & Hrudey, 2006; Australian

Department of Health, 2012). All these factors mean that, in certain assessment contexts, the absence of direct epidemiological evidence about the health risk of exposure to air pollution is an important limitation. In some of the most highly polluted regions of the world, there is a severe lack of direct epidemiological evidence. Studies are urgently needed in these areas, because the health response per unit change in air pollution at such high levels may differ from that seen in countries with lower pollution levels.

Health effects

There are now accepted techniques to derive estimates of health effects in India by reference to health effects studies done elsewhere. Similar techniques, which rely on exposure-response analyses, are widely utilized in policy across many environmental health risks, including those in water, toxic chemicals, workplace pollutants, etc. The health burden from ambient and household air pollution exposures is no longer thought to be limited to chronic and acute respiratory outcomes in men, women, children and the aged, as it is generally accepted that there are also impacts on ischemic heart disease, stroke, cataracts, and lung cancer. In addition, there is increasing evidence of adverse pregnancy outcomes, TB, asthma exacerbation, other cancers, and cognitive impairments. Just as with tobacco smoking, which produces the same set of impacts, air pollution needs now to be considered within public health programs concerning both non-communicable and communicable diseases. The disease burden estimates for air pollution have been standardized through the development of what are now called “integrated exposure-response” (IER) relationships that uses the vast health literature of health effects from outdoor air pollution (mostly in developed countries); although there is some degree of uncertainty in the estimation, it is unchanged mostly. Active smoking with the growing literature documenting effects through second-hand tobacco smoking (SHS) and household air pollution. These now show a gradual rise in risk for five major categories of disease (lung cancer, heart disease, stroke, chronic obstructive pulmonary disease, and child pneumonia) over nearly a factor of 1000 in exposure – with outdoor air pollution levels at the lower end, active smoking at the highest levels, and second-hand smoke and HAP being intermediate.

OBJECTIVE

The main purpose of this study is to answer policy questions about the health impacts of ambient and indoor air pollution exposure. The broad questions that were addressed during this analysis are as follows:

1. What is the public health burden associated with short and long-term exposures to air pollution?
2. What are the changes in health impacts due to differential urban and rural exposures in West Bengal?
3. How do health outcomes of air pollution exposures vary due to various demographic and socio-economic factors?
4. What are the major causes of health burden in these regions?

The results from this analysis can be used in an estimation of the economic value of health benefits resulting from policy towards air pollution abatement measures. The knowledge gained through this study can also be used to improve policies, such as increasing the stringency of air quality standards.

METHODOLOGY

Study area

The study was conducted in 7 locations - Kolkata, Howrah, Asansol, Haldia, Barrackpore, Bardhhaman and Barasat in West Bengal. The area covers 23˚14´- 22˚04´ N, 88˚24´-86˚45´ E. These regions experience tropical climate with summer (March-May, average temp 33-35 degrees), winter (December-February, 14-17 degrees) and pronounced monsoon (June-August, 1050-1800 mm). In these regions, there are many medium to large-scale coal-based thermal power plants. Four of the important ones are: New Cossipore station (100MW, $PM_{2.5}$ and SO2 emission rate (ER): 91 and 780 tons y–1), Southern station (135 MW, $PM_{2.5}$ and SO2 ERs: 49 and 2632 tons y–1), Budge Budgestation (750 MW, $PM_{2.5}$ and SO2 ERs: 75and 4914 tons y–1) and Titagarh station (240 MW, $PM_{2.5}$ and SO2 ERs: 28 and 1638 tons y–1) (ADB, 2005). The megacities have a huge vehicular population of ~3.25 million (as of 2016), of which ~65% is comprised of gasoline-fueled passenger cars and 2-wheelers. Other major sources of air pollution are road dust, open burning of municipal solid waste in fields, asphalt hotmixing plants, diesel locomotive emissions, domestic cooking from houses (wood, LPG, and kerosene) in slums, small-scale industrial/commercial establishments for lead (Pb) smelting, iron (Fe) foundries, rubber factories, battery, paper producing factories with wood/oil/coal boilers, coal-fired brick kilns, etc. (ADB,2005).

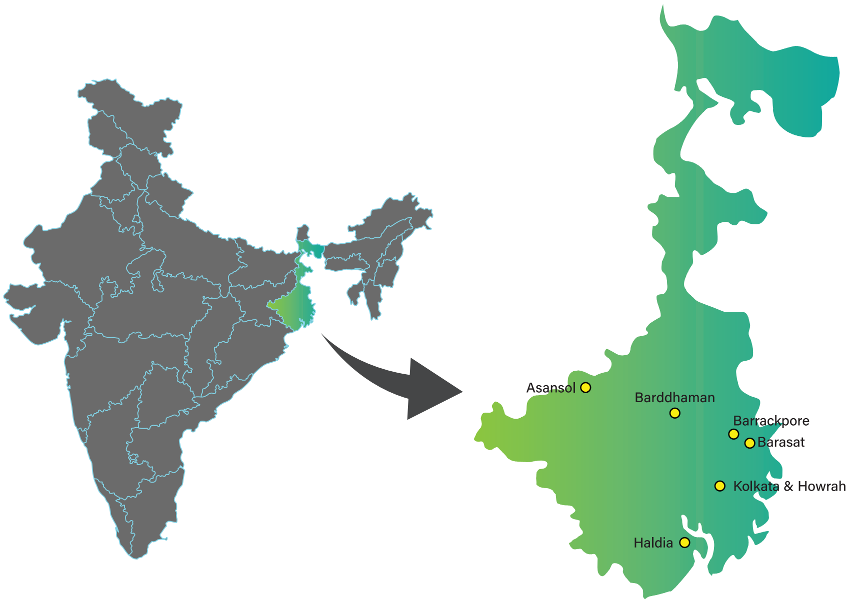


Figure 1: Study locations of the survey areas in West Bengal

West Bengal is located in the eastern part of the Indo-Gangetic Plain (IGP). About 51% of its air pollution is caused by vehicular traffic, 27% by industrial pollution, 17% by crop burning and 5% by Diwali fireworks (Rawat et al., 2019). An estimated 1.25 million (1.09-1.39) premature mortalities in India were attributable to the exposure of $PM_{2.5}$, which were 12.5% of total deaths. India also contributed to 26.2% of global DALYs due to air pollution. About 42.8% of these mortalities are estimated to occur in north and central IGP (Balakrishnan, 2017). Breathing of particulate matter and gaseous pollutants for a long time can lead to respiratory and cardiovascular diseases such as asthma and breathlessness (57%), TB and lung infection (24%) (WHO, 2018). In India, Kolkata ranked 2nd among the most polluted cities (WHO, 2018). Here, an estimated mortality of over 6500 per year has been recorded due to air pollution (Gurjar and Nagpure, 2015). The Indian Medical Association in a survey in 2017 reported that, 85% of total patients admitted to dispensaries were suffering from cardiovascular and respiratory disease. The huge vehicular population in the southern part of West Bengal is related to high concentrations of black carbon (BC), organic carbon (OC) and aerosol sulfate. As an example, BC surface mass densities ranging from 5 to 28 µgm−3, with values as high as 22–35 µgm−3 in winter have been reported in Kolkata (Chatterjee et al., 2013; Pani and Verma, 2014; Talukdar et al., 2016, Singh et al., 2021). Similarly, very high values of OC (4–145 µgm−3; seasonal averages; Chowdhury et al., 2007; Chatterjee et al., 2013) and sulphate (2–5 µgm−3; Chatterjee et al., 2013) have also been reported. Pollutants from central and north-western IGP are transported towards eastern IGP and get deposited around Kolkata city and other districts of West Bengal (Srinivas and Sarin;2014).

Survey description

A survey was conducted in the months of December and January of 2021-22. A standard questionnaire was prepared, where the binary responses were recorded about household and socio-demographic status, smoking habit and frequency, and prevalence of different health symptoms for the respondents, classified into upper (URS) and lower (LRS) respiratory symptoms. For this study, we included wheezing, asthma, earache, tachycardia and hypertension in URS, whereas sore throat, sinusitis, runny nose, sneezing, nasal congestion, cough, chest discomfort and breathlessness in LRS.

Table 1: Characteristics of study participants

CHARACTERISTICS	URBAN	RURAL
TOTAL PARTICIPANTS : 1155	576	579
GENDER		
MALE	368	301
FEMALE	208	278
AGE		
YOUNG (UPTO 20 YEARS)	38	47
ADULT (21–50 YEARS)	388	285
AGED (> 50 YEARS)	150	147
OCCUPATION		
PROFESSIONAL	391	143
ENTREPRENEUR	67	240
WORKER	118	186
SES		
HIGH (5-11)	126	96
MIDDLE (12-18)	268	252
LOW (19-25)	182	231

A total of 1155 people were interviewed from 7 different locations across southern regions of West Bengal; Kolkata, Howrah, Bardhaman, Barrackpore, Haldia, Asansol and Barasat. 576 (49.87%) responses were recorded from urban, whereas 579 (50.13%) were collected from rural regions. These data were collected from the insights of age, gender, occupation and socio-economic condition (SES). For both rural and urban, survey data were classified into three age categories; young as 20 years, adult as 21-50 years and aged above 50 years. Occupation classes comprised of professionals that included people from service, white-color jobs and retired, entrepreneurs including shop-owners, tailors, pottery makers, etc, and the working-class comprised of laborers, industrial workers and farmers. Various responses recorded by occupation, education and family income were classified into socio-economic categories by Kuppaswamy and Udai Pareekh's SES scale for 2019 (Wani, 2019). This scale has a range of 3-29. In this survey, the SEC scale ranged from 5 to 25 and was classified into three categories- low SES (5-11), middle SES (12-18) and high SES (19-25). For the rural region, the data were recorded by; gender; male (51.97%) and female (48.03%), age; young (8.12%), adult (66.49%) and aged (25.39%), occupation; professionals (24.7%), entrepreneur (41.45%) and worker (32.12%) and three SES categories as high (16.58%), middle (43.52%) and low (39.89%).

For the urban region, 63.9% male and 36.1% female respondents were surveyed by age categories; 6.59% young, 67.36% adult and 26.05% aged. Similar to rural, urban occupation data is distributed into professionals (67.88%), entrepreneurs (11.63%) and workers (20.49%) and for SES, it's distributed into 21.88% high, 46.52% middle and 31.6% low.

The survey was conducted at the household level for rural and urban regions, shops close to and away from roads, and residents near an industry or power plant. Participants living in a locality for more than 10 years were surveyed to observe the long-term effects of $PM_{2.5}$. After the questionnaire was administered, signatures and declarations of consent were recorded for each respondent.

Exposure assessment

Aerosol optical depth (AOD) from Moderate Resolution Imaging Spectroradiometer (MODIS) was retrieved by Multi-angle Implementation of Atmospheric Correction (MAIAC) algorithm to surface $PM_{2.5}$ using a dynamic scaling-factor from Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA-2) data. The satellite-derived daily (24-h average) and annual $PM_{2.5}$ showed an R^2 of 0.8 and 0.97 and root mean square error of 25.7 and 7.2 $\mu g/m^3$, respectively against surface measurements from the Central Pollution Control Board India network (Dey et al., 2020).

A year Annual $PM_{2.5}$ exposure data were was obtained at 1x1 km resolution using the geo-locations from the survey regions. During the survey, it was assumed that respondents within each sq. km region were exposed to similar air pollution exposure. 2021 annual averaged $PM_{2.5}$ dataset was used for short-term exposure for every survey location and annually-averaged data of 2, 5, 10 and 20 years were was used to assess the long-term exposure. For every location, $PM_{2.5}$ was extracted using QGIS (v 3.18.3) software by obtaining the maximum, minimum, standard deviation and mean. Survey number from every location was known, therefore random $PM_{2.5}$ values were generated in Python between maximum and minimum ranges using the standard deviation for that location. All the data were clubbed to obtain the datasets for urban and rural regions. Spatial plots for long and short-term $PM_{2.5}$ exposure for West Bengal were made in QGIS as well.

Statistical analysis of the data

All the statistical analyses were done in Python. Health data (symptoms), $PM_{2.5}$ exposure and other confounder variables were incorporated into the logistic regression model to find the association. The coefficients from the model outcome were used to calculate the odds ratio for each symptom. OR for every 10 $\mu g/m^3$ increment of $PM_{2.5}$ at short-term (1 year) exposure was calculated for URS (Appendix) and long-term (2, 5, 10 and 20 years) exposure for LRS symptoms for both urban and rural data with lower and upper limits of 95% confidence interval.

A similar analysis was performed for different classes of age, gender, occupation and SES as well. LRS symptoms are associated with chronic obstructive pulmonary disease (COPD), lower respiratory infection (LRI) and type-2 diabetes mellitus (T2DM). Relative risk (RR) was calculated for long-term exposure to these diseases using the MR-BRT exposure-response function and counterfactual $PM_{2.5}$ (Appendix).

During the analysis, the normality and the heterogeneity of variance assumptions were verified and the results were found to be satisfactory. The general characteristics of the entire cohort of the population surveyed are reported in Table 1, from the characteristics of survey data in different socio-demographic groups.

Regression model

At first, a univariate regression model was performed to find the correlation between different health outcomes and $PM_{2.5}$ exposure, both in the short and long-term. But the results we obtained were insignificant, and negative correlations were obtained for a few symptoms as well. In order to find the 'true' association between health outcomes and $PM_{2.5}$ exposure, a multivariate logistic regression model was used using the socio-demographic factors as a confounder variable. Except for $PM_{2.5}$, all other parameters were converted to binary responses and the following model was estimated,

$$\mathbf{H_{ild} = \beta_1 * HH_{il} + \beta_2 * Smoke_{il} + \beta_3 * SES_{il} + \beta_4 * PM_{2.5ilt} + \mathcal{E}_{il}}$$

Here, H_{ild} is the symptom of disease d for a person i at location l. HH_{il} includes all household parameters such as the number of residents at the household, fuel use type, kitchen location, presence of chimney, use of dhoop and pesticides at location l, $Smoke_{il}$ is the smoking status of person i at location l, it incorporates smoking habit, type and frequency, smokers in family and SES_{il} includes gender, per capita income, occupation and educational qualification of person i at location l. $PM_{2.5}$ilt is the ambient $PM_{2.5}$ exposure for the person i at location l. This incorporates both long and short-term (t) exposure (short-term exposure was considered as $PM_{2.5}$ annual average exposure of 2020 and 2021 whereas long-term exposure was taken as 5, 10 and 20 years annual mean data). β_{1-4} estimates the impacts of different socio-demographic factors on the development of different symptoms and ε_{il} is the error term. All the variables were split into train-test datasets (70% train & 30% test). A strong coefficient of determination (R^2) implies that health outcomes are strongly dependent on other confounder variables as well as $PM_{2.5}$ exposure and any change in that could lead to a change in the outcome even at a higher degree. All the steps were 10-fold cross-validated using the first 9-fold to train the dataset and the remaining fold to test the model. R^2 was noted after running a 10-fold CV.

RESULTS AND DISCUSSION

Regional variations in $PM_{2.5}$ exposure

The air of all the survey locations seem to be highly polluted both in terms of long and short-term exposures. During 2015-16, India experienced high ambient air pollution events and West Bengal was no exception to it. It is evident from the study that 5 and 10 years' average $PM_{2.5}$ levels were the highest, followed by 20 years' average $PM_{2.5}$ concentration and lower values were obtained from short-term exposures (2 years' average) due to implementation of the lockdown in India. For short-term exposure, the $PM_{2.5}$ concentrations ranged between:

- 75.93 and 61.24 $\mu g/m^3$ in Kolkata,
- 77.5 to 67.5 $\mu g/m^3$ in Howrah,
- 85.4 to 66.4 $\mu g/m^3$ in Asansol (in Paschim Bardhaman district),
- 82.4 to 77 $\mu g/m^3$ in Barddhaman,
- 84.8 to 75.3 $\mu g/m^3$ in Barrackpore (North 24-Parganas),
- 53.5 to 41.3 $\mu g/m^3$ in Haldia (Purba Medinipur), and
- 80.8 to 64.7 $\mu g/m^3$ in Barasat (North 24 Parganas).

Similarly, for long-term exposure, $PM_{2.5}$ levels in ambient air varied between

- 81.2 and 74 $\mu g/m^3$ in Kolkata,
- 79.7 to 75.3 $\mu g/m^3$ in Howrah,
- 85.2 to 83 $\mu g/m^3$ in Asansol,
- 76.7 to 72.1 $\mu g/m^3$ in Barddhaman,
- 76.6 to 72.7 $\mu g/m^3$ in Barrackpore,
- 81.5 to 78.3 $\mu g/m^3$ in Haldia, and
- 78.7 to 73.3 $\mu g/m^3$ in Barasat.

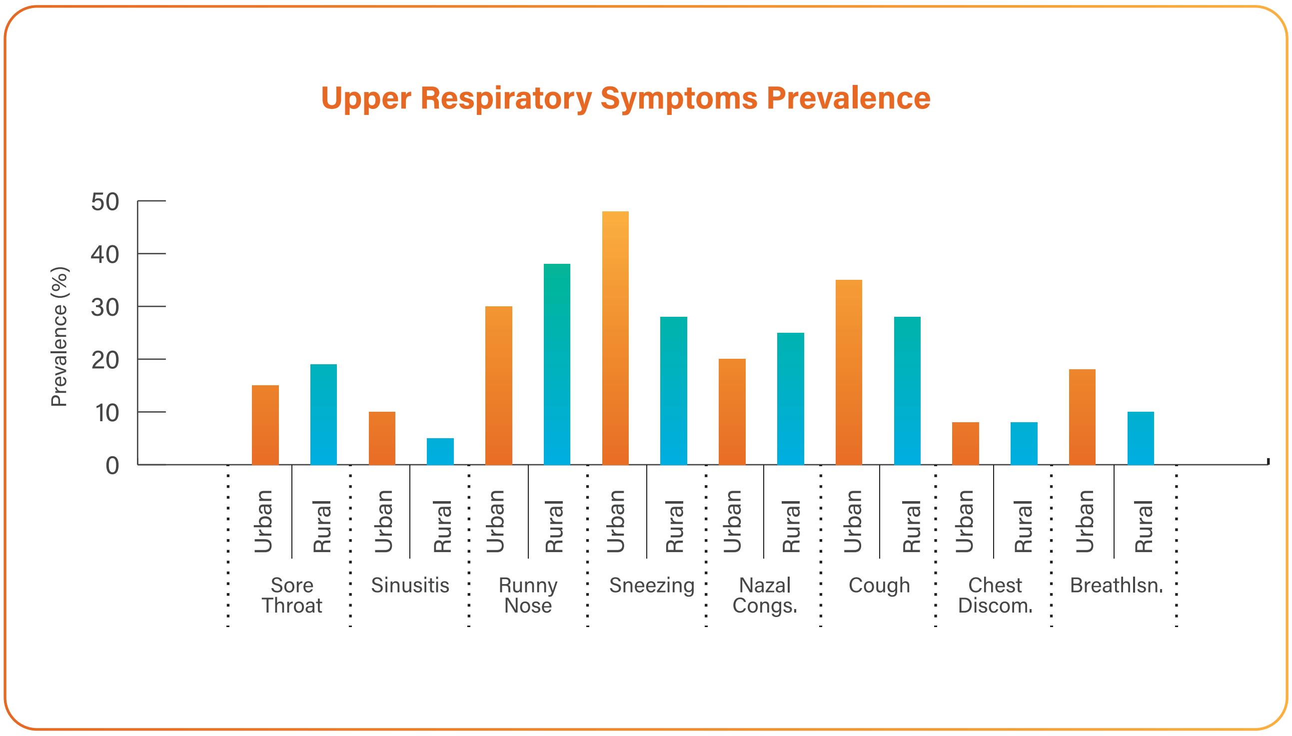
Thus, the $PM_{2.5}$ levels were appreciably higher in the urban regions compared to rural areas.

Table 2: The average short and long-term $PM_{2.5}$ concentrations in ambient air of the survey locations in urban and rural regions

Study locations	**Past 1yr ($\mu g/m^3$)**	**Past 2yr ($\mu g/m^3$)**	**Past 5 yr ($\mu g/m^3$)**	**Past 10 yr ($\mu g/m^3$)**	**Last 20 yr average ($\mu g/m^3$)**
URBAN AREAS					
KOLKATA	71.5	64.9	74.6	80.2	75.3
HOWRAH	75.9	67.8	75.1	78.5	73.8
BARRACKPORE	80.6	70.5	75.8	78	73.5
BARDHAMAN	80.3	69	74.1	-	72
RURAL AREAS IN					
ASANSOL	80.6	74.3	82.6	85.8	81.5
BARDHAMAN	80.2	69.3	73.7	74	71.1
HALDIA	49.2	57.8	74.4	83.6	77.5
BARASAT	73.8	66.1	74.2	78.8	74.1
HOWRAH	69.4	66.5	76.9	82.1	76.5

A comparison of the prevalence of respiratory and associated symptoms between urban and rural people

The distributions of the prevalence of the respiratory and associated symptoms in urban and rural regions are shown in Figure 2. Overall, runny nose, cough and sneezing were the more prevalent respiratory symptoms; hypertension and earache were the more common cardiovascular and associated symptoms, respectively. URS were more common in rural regions. In contrast, LRS were more prevalent in urban areas. In urban regions, $PM_{2.5}$ comprised of more complex chemical species due to the adjacency of industries, coal-based thermal power plants and vehicular traffic, and hence, the long-term effects are more prominent in the urban population, whereas rural regions are dominated by household emissions. This could also be the probable reason for higher prevalence of URS rather than LRS among the rural people.



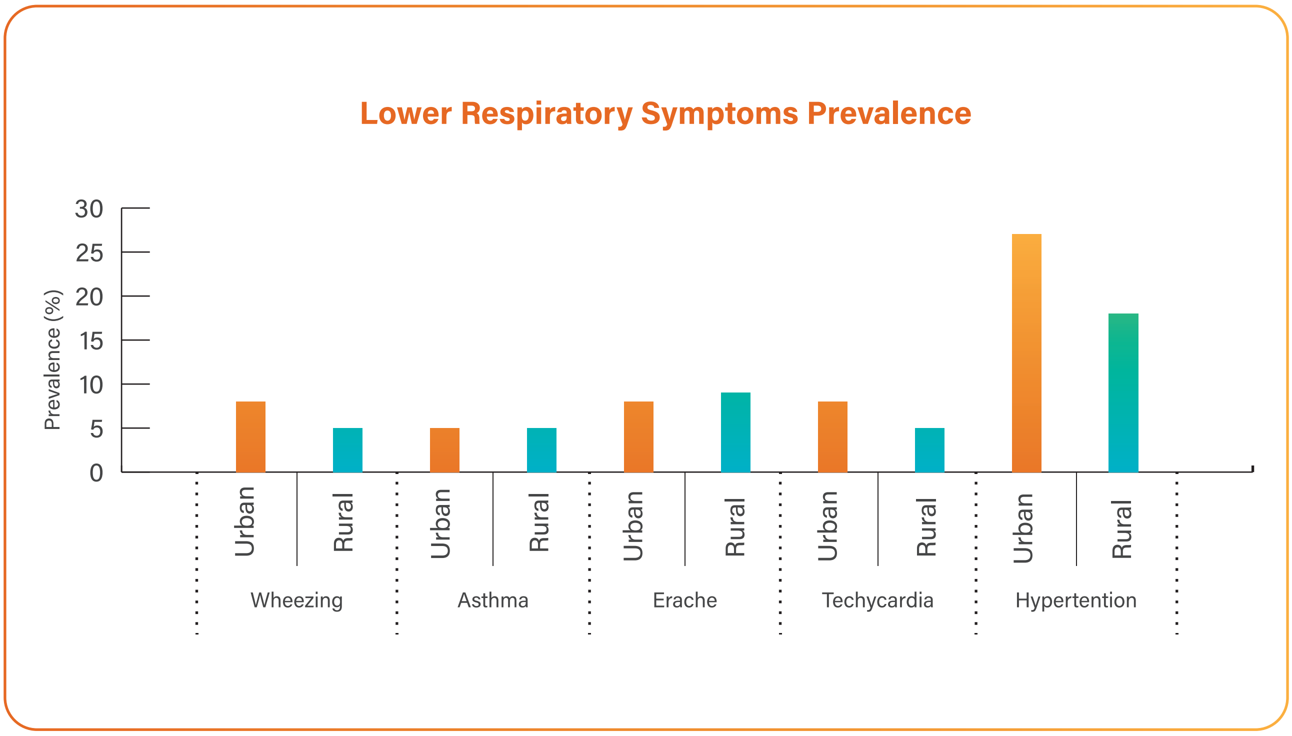


Figure 2: A comparison of the regional distribution of the prevalence of respiratory symptoms between urban (Red) and rural (Blue) areas surveyed in this study.
[Nasal Congs. = Nasal Congestion, Chest discm. = Chest Discomfort, Breathlsn. = Breathlessness]

The prevalence of respiratory and associated symptoms between urban and rural people in relation to age

In the urban group, URS were most prevalent in young people within the age of 20 years. About 31% participants of this age group had experienced URS. In contrast, the aged, 50+ years people in the rural areas suffered most (27.4%) from URS (Figure 3).

Like URS, LRS symptoms were more prevalent in rural areas. Interestingly, aged (50+) persons displayed highest prevalence of LRS both in rural and urban areas (Figure 3).

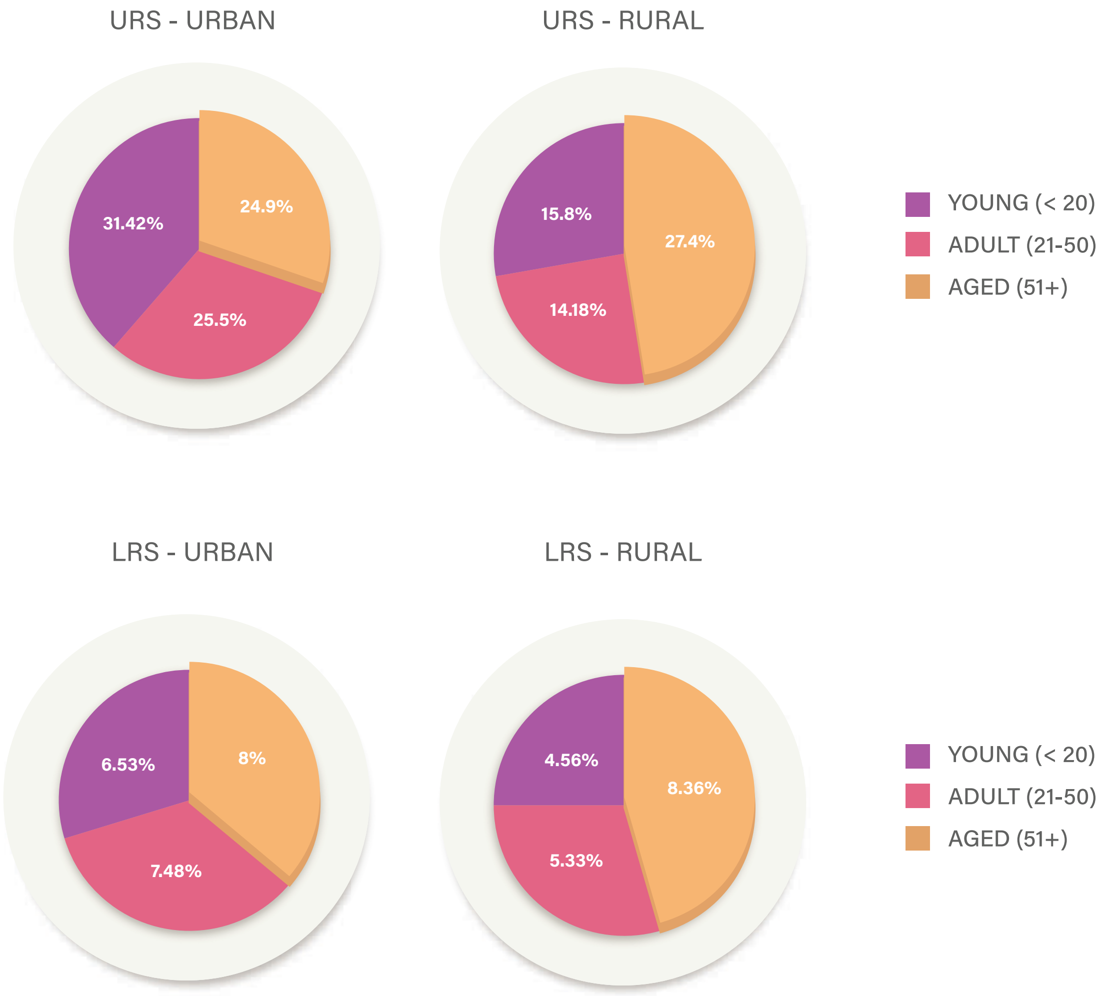


Figure 3: Prevalence of respiratory and associated symptoms in relation to age

The prevalence of symptoms between urban and rural people in relation to gender

In both urban and rural areas, females developed significantly higher upper respiratory symptoms than the males (Figure 4), whereas the LRS symptoms were more obvious in males than females. Males and females have developed more URS and LRS symptoms in urban regions than in rural. For short-term exposure, indoor air pollution plays a significant role as compared to ambient air pollution; hence, females were more affected. But, long-term exposure, which is broadly known as ambient air pollution, was responsible for the development of LRS symptoms mostly in surveyed men who spend more time outdoors.

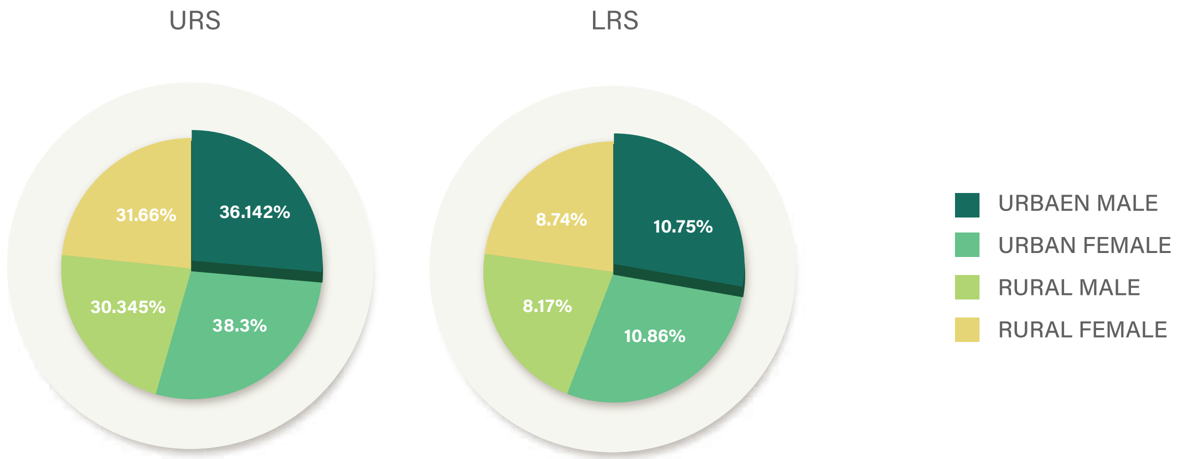


Figure 4: Prevalence of respiratory and associated symptoms in relation to gender

The prevalence of symptoms in relation to occupation

The prevalence of health symptoms has been analyzed in relation to different occupational categories. Professionals were more affected by air pollution exposure in both the regions compared to entrepreneurs and workers (Figure 5). For URS, professionals (48.6%) developed higher health outcomes than other occupational categories, especially in rural regions. For LRS, the development was significantly higher in professionals (29.17-40%) compared to entrepreneurs and workers in both regions. Duration of $PM_{2.5}$ exposure is a key component in the development of various respiratory health outcomes, and it has been evident from the higher prevalence observed in professionals (Figure 5).

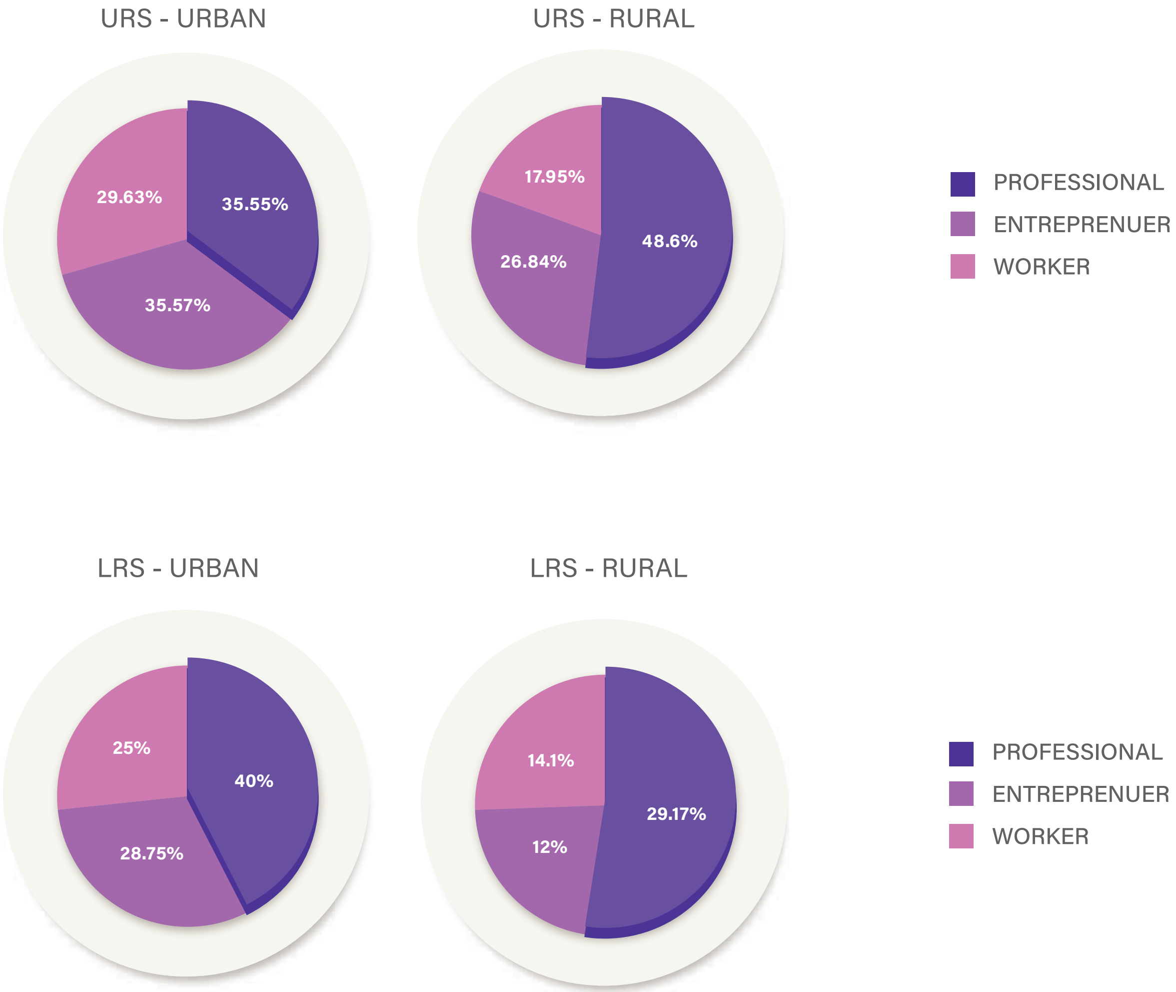


Figure 5: The prevalence of respiratory symptoms in relation to occupation of the participants

The prevalence of symptoms in relation to socio-economic status of the participants

The prevalence of URS was higher in high and middle SES for urban regions, whereas for rural regions, the prevalence was higher in middle and low SES (Figure 6). A significant difference in prevalence was found in low SES people (38.72%) compared to middle and high SES for URS symptoms in urban regions and for high SES (13.13%) compared to middle and low SES for LRS symptoms in rural regions. Similar trend was observed in urban regions for LRS as well but in rural regions, high and low-SES people developed more symptoms.

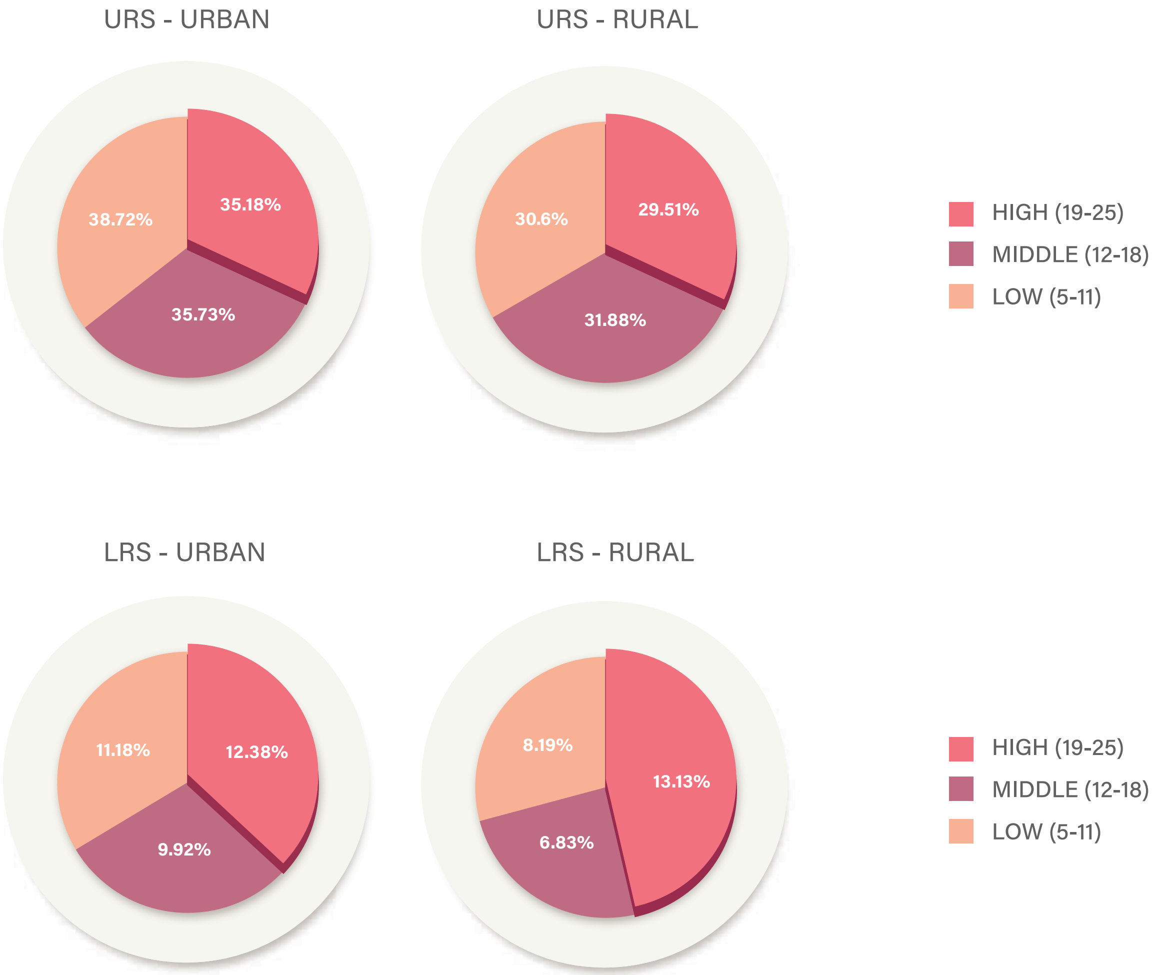


Figure 6: The prevalence of respiratory symptoms in relation to socio-economic status (SES) of the participants

Thus, working status and income level play key roles in the development of health outcomes vis-à-vis air pollution exposures.

Association between particulate air pollution ($PM_{2.5}$) exposure and health outcomes

Prevalence of respiratory symptoms

The effects of short and long-term exposure to $PM_{2.5}$ on URS and LRS were calculated for urban and rural data. URS showed a strong odds ratio (OR) with every 10 $\mu g/m^3$ increment of short-term $PM_{2.5}$ exposure with cough (OR: 1.47, 95% CI: 1.21-1.73) and sneezing (1.35, CI: 1.29-1.41). The association was stronger in urban population for cough (1.54, CI: 1.47-1.62) and nasal congestion (1.51, CI: 1.39-1.62). Higher odds (OR) signify that $PM_{2.5}$ exposure was strongly associated with the URS prevalence among the rural participants.

The survey locations in urban regions were adjacent to thermal power plants and heavy road traffic. Hence, the air pollution concentration was higher in these locations. Therefore, people in these regions inhale more air pollutants and were prone to the development of respiratory symptoms (mostly URS) compared to survey locations in rural regions where respondents reside away from the industries and motorized road traffic. The chemical characteristics of the pollutant source-types are obviously different in the urban and rural survey locations.

Effects of long-term exposures to $PM_{2.5}$ (20, 10 and 5 years) were observed on the development of LRS and showed significant positive association. All the symptom prevalence showed increasing OR with increasing long-term exposure among rural populations (Figure 7). Association with $PM_{2.5}$ exposure was found in hypertension (1.06, CI: 0.89-1.23) for 20 years, asthma (1.03, CI: 1-1.06) for 10 years, followed by asthma (1.98, CI: 1.24-2.73), wheeze (1.75, CI: 1.13-2.36) and tachycardia (1.3, CI: 0.85-1.75) for 5 years.

The ORs for LRS in the urban population were noticeable (Figure 7) for wheeze (1.45, CI: 1-1.9), earache (1.43, CI: 0.92-1.94), tachycardia (1.17, CI: 1.04-1.31) and asthma (1.04, CI: 1-1.09) for 20 years; asthma (1.48, CI: 1.43-1.53) and hypertension (1.19, CI: 1.14-1.24) for 10 years; and asthma (1.14, CI: 1.1-1.19) and earache (1.02, CI: 0.51-1.53) for 5 years.

For risk assessment, the relative risk for COPD, lower respiratory infections (LRI) and type 2 diabetes mellitus (T2DM) were calculated. COPD showed highest risk for both 20 years' (1.61, CI: 1.6-1.62) and 10 years' (1.65, CI: 1.63-1.67) $PM_{2.5}$ levels. The symptoms of potentially life-threatening COPD were very common in the survey population and its strong association (OR) with $PM_{2.5}$ is indicative of high relative risk (RR). Likewise, LRI showed strong associations with the average $PM_{2.5}$ levels for the past 20 (1.45, CI: 1.44-1.46) and 10 years (1.47, CI: 1.44-1.5).

Interestingly, diabetes also showed a strong positive association with the prevailing $PM_{2.5}$ levels (1.29, CI: 1.28-1.3) in the past few years. Therefore, type 2 diabetes among the people in the study areas appears to causally related to, among others, high level of particulate pollution in ambient air. However, the number of participants was not large enough for risk calculation of both LRI and diabetes.

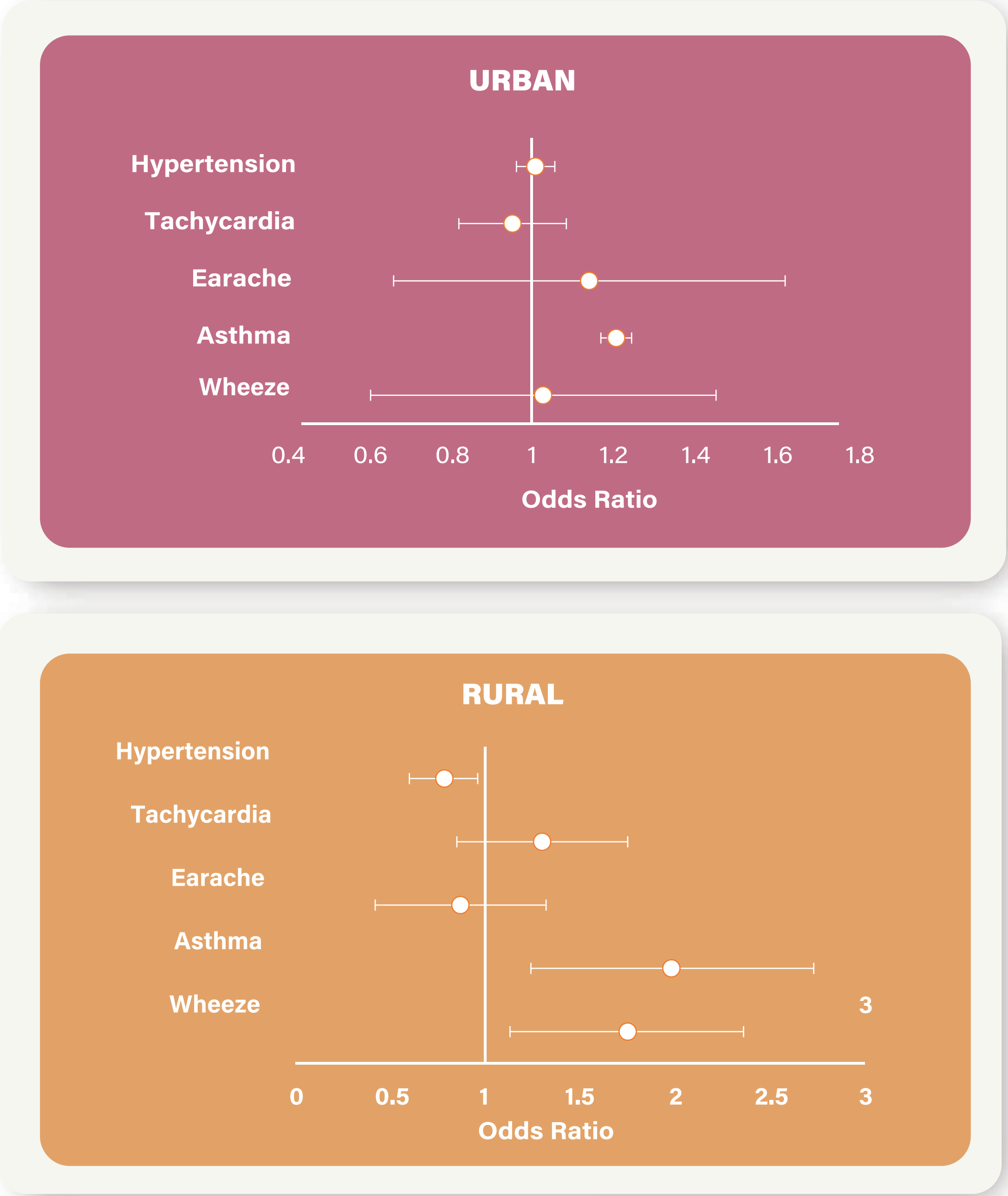


Figure 7: Odds ratios for the lower respiratory symptom prevalenceamong urban and rural regions. The values are depicted as Odds ratio with (95% confidence interval) for health outcomes.

It is evident from the questionnaire that the use of solid fuels (such as biomass, coal and kerosene) was greater in rural households, whereas LPG and electrical inductions were more in urban regions. The urban population is also exposed more to emissions from vehicles, industries and power plants, along with construction and road dust when prolonged exposure is concerned; whereas open burning in the outskirts also contributes to the total pollution at a significant level (Upadhyayet al. 2018). Along with this, consumption of smoking substances, occupation, education, kitchen location and presence of chimney, and use of pesticides at home also played key roles. People in rural regions mostly consume beedi and gutka, whereas in urban regions they smoke cigarettes and also use phenyl to clean the house and floors. Rural households mostly don't use chimneys, and the kitchen is adjacent to living rooms, so they are more exposed to indoor air pollution than urban households (Hou et al., 2021). The literacy and per capita income were more for the urban population and these variables strongly signify the higher association of short and long-term $PM_{2.5}$ with URS and LRS prevalence for urban and rural population.

Health impact with relation to gender

Short and long-term exposures to males and females were obtained for urban and rural regions. Women were more vulnerable to short-term exposure than men. In urban regions, for every 10 $\mu g/m^3$ increment of $PM_{2.5}$ chest discomfort (1.97, CI: 1.73-2.2) showed the highest association followed by runny nose (1.38, CI: 1.14-1.63) and cough (1.13, CI: 0.91-1.35) in women compared to a strong association for cough (1.95, CI: 1.83-2.07) and nasal congestion (1.32, CI: 1.19-1.44) in men.

Similarly in rural regions, a higher association was observed for sore throat (1.93, CI: 1.61-2.25), breathlessness (1.72, CI: 1.11-2.33), followed sinusitis (1.53, CI: 1.28-1.79), runny nose (1.5, CI: 1.36-1.65) and sneezing (1.29, CI: 1.14-1.44) in women compared to higher association for cough (1.56, CI: 1.4-1.73), breathlessness (1.39, CI: 0.5-2.28) and sneezing (1.07, CI: 0.98-1.16) in men.

Long-term exposure also showed positive association with respiratory symptoms in males and females in both regions. Adverse health effects were more prevalent in urban regions and in women than the men (Figure 8). In women, wheeze (1.6, CI: 1.08-2.12) showed the highest association for every 10 $\mu g/m^3$ increment of $PM_{2.5}$ followed by ear ache (1.48, CI: 0.94-2.02), tachycardia and asthma (1.32, CI: 1.11-1.53); whereas for men asthma (1.15, CI: 0.85-1.45) showed the highest association followed by hypertension (1.12, CI: 1.07-1.17) and tachycardia (1.1, CI: 0.99-1.03). Similar trends were seen in rural regions as well, where women were more vulnerable than men (Figure 8). In female, wheeze (1.56, CI: 0.83-2.28) and tachycardia (1.55, CI: 1.14-1.95) showed highest odds followed by earache (1.35, CI: 0.82-1.89) and hypertension (1.22, CI: 1.13-1.32); whereas in male, earache (1.02, CI: 0.56-1.48) showed positive odds. In both the regions, risks for COPD, LRI and diabetes were identical in males and females; but the risks were slightly higher in rural population. In both the sexes, COPD was higher in rural (1.63, CI: 1.62-1.64) than in urban (1.62, CI: 1.59-1.65), similarly for LRI (1.46, CI: 1.44-1.48 for rural and 1.44, CI: 1.43-1.45 for urban) and diabetes having the lowest risk (1.29, CI: 1.27-1.31)

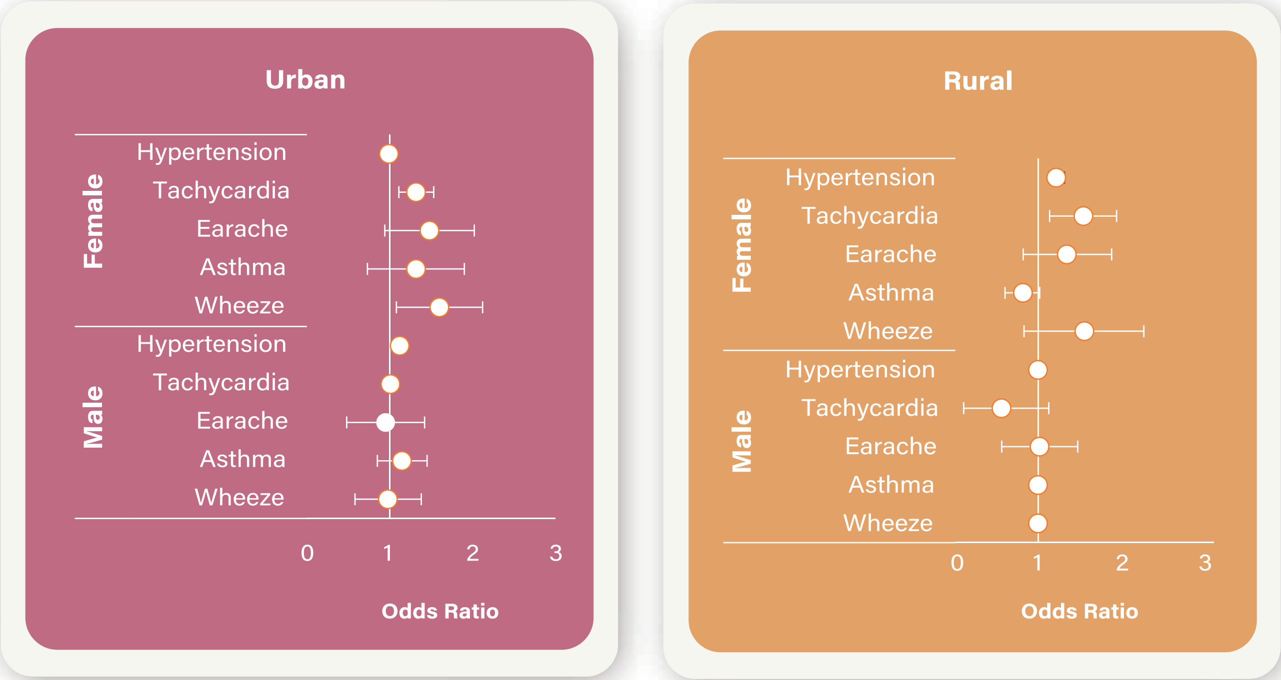


Figure 8: Distribution of odds ratios for cardiovascular and respiratory symptoms by gender of the participants

In the short-term, females are more exposed to indoor air pollution mostly in rural regions where solid fuel is used for cooking purposes, which could emit black carbon. Women inhale more polluted air as they are directly exposed to it (Bates et al., 1992). At a large time-scale, indoor air pollution could also be a reason for the development of adverse health outcomes for women than men, especially in rural and suburban regions, where the chimney is not available in most households and kitchens are adjacent to living rooms (Roy et al., 2006).

Impact of age

Short and long-term exposures to different age categories were obtained for urban and rural regions. Aged and adults were more vulnerable to air pollution, and exposure-response was higher in urban regions than rural (Table 3). In urban areas, breathlessness showed the highest association with aged (50+ year) people (1.8, CI: 1.56-2.04) for every 10 $\mu g/m^3$ increment of $PM_{2.5}$ people. It was followed by runny nose (1.72, CI: 1.58-1.76) and cough (1.09, CI: 1-1.18) in adults (within 50 years). Similarly in rural regions, higher association was found in aged people for breathlessness [1.5 (0.89-2.1)] and cough [1.07 (0.87-1.27)], followed by runny nose (1.25, CI: 1.16-1.34) and nasal congestion (1.02, CI: 0.96-1.08) in adults. A significant association was not observed in the young population. In the aged population, strong odds were found in asthma (1.77, CI: 1.48-2.07) followed by tachycardia (1.39, CI: 1.07-1.77), ear ache (1.24, CI: 1.02-1.45) compared to wheeze (1.3, CI: 1.02-1.56) and tachycardia (1.2, CI: 1.03-1.37) in adults and asthma (1.21, CI: 0.95-1.47) in young population of urban regions for long-term exposure. Similar patterns were found in rural regions as well, where prevalence was highest in aged people for tachycardia (2.08, CI: 1.82-2.33), asthma (2.02, CI: 1.58-2.45) and hypertension (1.47, CI: 1.35-1.59) followed by adults for asthma (1.72, CI: 1.31-2.14), ear ache (1.67, CI: 1.47-1.87) and hypertension (1.59, CI: 1.37-1.81), with the lower association was observed in young population for wheeze (1.26, CI: 1.01-1.5) and ear ache (1.22, CI: 0.79-1.65). In both the regions, risks for COPD, LRI and diabetes were identical in all age categories; but the risks were slightly higher in the rural population. Among all the age categories, COPD was higher in rural (1.63, CI: 1.6-1.65) than in urban (1.62, CI: 1.6-1.64), similarly for LRI (1.46, CI: 1.43-1.49 for rural and 1.44, CI: 1.43-1.45 for urban) and diabetes having the lowest risk (1.29, CI: 1.28-1.3).

Table 3: Distribution of odds ratios by age. Odds in 'red' is statistically less significant

AGE	SYMPTOMS	ODDS RATIO (URBAN)	ODDS RATIO (RURAL)
Young (< 20)	Wheeze	1.26 (1.01-1.5)	1
	Asthma	1	1.21 (0.95-1.47)
	Ear ache	1.22 (0.79-1.65)	1
	Tachycardia	1	0.76 (0.55-0.97)
	Hypertension	0.85 (0.69-1.01)	1
Adult (21-50)	Wheeze	1.14 (0.78-1.5)	1.3 (1.02-1.56)
	Asthma	1.72 (1.31-2.14)	1.1 (1.01-1.19)
	Ear ache	1.67 (1.47-1.87)	1.09 (0.64-1.54)
	Tachycardia	1	1.2 (1.03-1.37)
	Hypertension	1.59 (1.37-1.81)	1.09 (0.64-1.54)
Aged (51+)	Wheeze	2.02 (1.58-2.45)	1.15 (0.99-1.3)
	Asthma	1	1.77 (1.48-2.07)
	Ear ache	1.19 (0.94-1.45)	1.24 (1.02-1.45)
	Tachycardia	2.08 (1.82-2.33)	1.39 (1.07-1.71)
	Hypertension	1.47 (1.35-1.59)	1.1 (1.05-1.16)

Aged people are less resistant to air pollution, especially when chronic respiratory diseases are concerned by long-term exposure. In urban regions, they breathe more polluted air, hence health burden is more (Brook et al., 2020). Adults are more exposed to outdoor air pollution and due to prolonged exposure, higher health outcomes have been developed in them compared to a younger population who are comparatively less exposed and also have strong resistance to short and long-term exposure (Tong et al., 2019).

Susceptibility in relation to occupation

Three occupational categories were classified in this analysis. Professionals were classed into “White color jobs” who were associated with mostly servicemen, businessmen, teachers, retired etc. Similarly, entrepreneurs were mostly shopkeepers, shop-owners who stayed near to a road for their living; and workers were laborers or hard workers, especially working in an industry, power-plants etc.

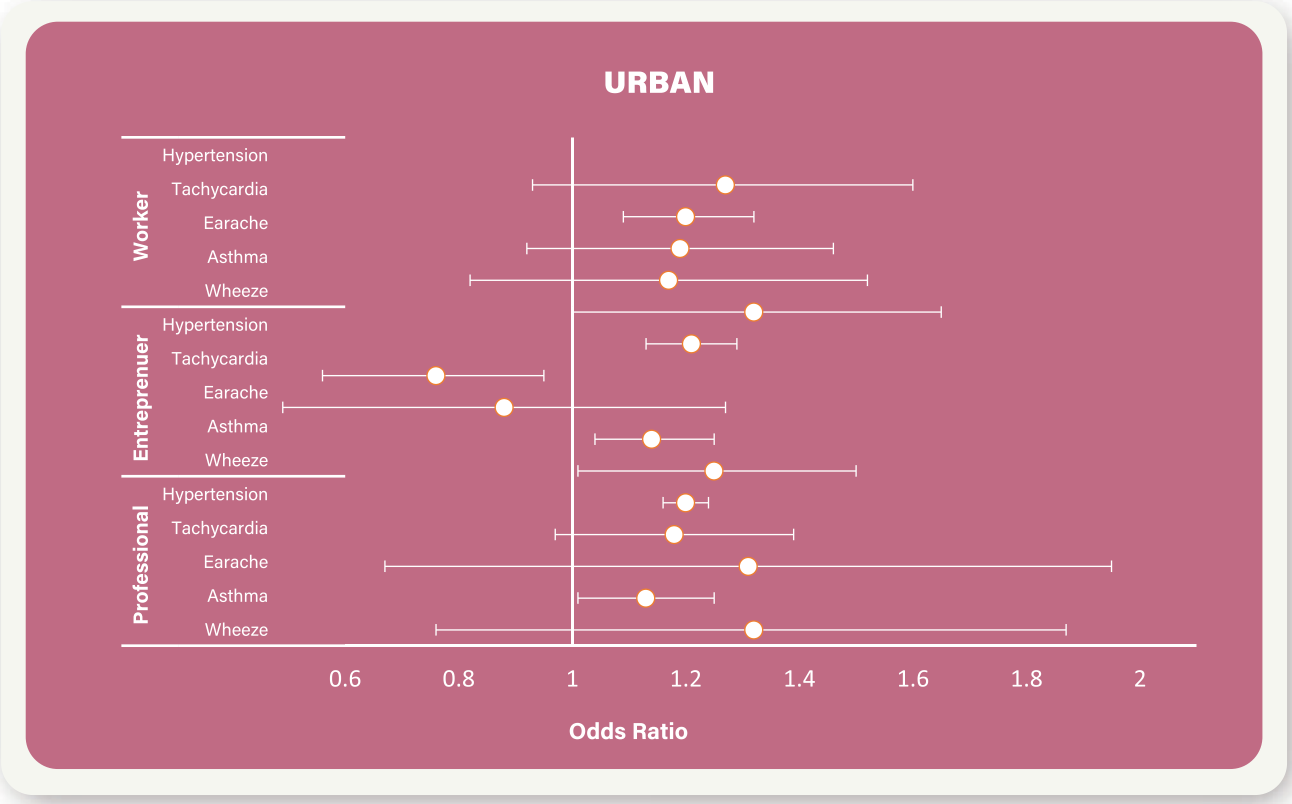
Air pollution exposure was observed in urban and rural regions. Professionals were more vulnerable in urban regions like workers were more in rural areas (Figure 9).

For short-term exposure in urban regions, strong association was found between sore throat (1.98, CI: 1.88-2.09), sinusitis (1.56, CI: 1.36-1.76) and cough (1.36, CI: 1.29-1.42) for professionals, high odds for breathlessness (1.85, CI: 1.42-2.28), cough (1.81, CI: 1.72-1.91) and sneezing in workers and breathlessness (1.85, CI: 1.6-2.02) in entrepreneurs. Similarly, in rural regions, higher association was observed in runny nose (1.65, CI: 1.59-1.7) and cough (1.44, CI: 1.22-1.66) for workers, followed by sneezing (1.7, CI: 1.43-1.97) in professionals and nasal congestion (1.28, CI: 1.19-1.36) in entrepreneurs.

For prolonged exposure, high association was found in urban professionals for wheeze (1.32, CI: 0.76-1.87) and earache (1.31, CI: 0.67-1.95) then for hypertension (1.2, CI: 1.16-1.24) and tachycardia (1.18, CI: 0.97-1.39); followed by wheeze (1.32, CI: 1.01-1.65), hypertension (1.27, CI: 0.93-1.6) and tachycardia (1.2, CI: 1.09-1.32) in workers, lower association was observed in entrepreneurs [1.25 (1.01-1.5) in wheeze and 1.21 (1.13-1.39) in hypertension].

In rural regions, strong associations were found in workers for tachycardia (2.12, CI: 1.97-2.27), hypertension (1.43, CI: 1.26-1.6) and asthma (1.32, CI: 0.75-1.89); followed by entrepreneurs for asthma (1.69, CI: 0.86-2.25), hypertension (1.68, CI: 1.56-1.8) and wheeze (1.34, CI: 1.02-1.66), while the lowest association was found in rural professionals for earache (1.53, CI: 1.29-1.76).

The risks for COPD, LRI and diabetes were similar in different occupational groups; but the risks were relatively higher in rural population. In both the sexes, COPD was marginally higher in rural (1.63, CI: 1.62-1.64) than in urban participants (1.62, CI: 1.59-1.65). Similarly, the risk for LRI was slightly higher in rural areas (1.46, CI: 1.44-1.48 for rural and 1.44, CI: 1.43-1.45 for urban) and diabetes showed moderate risk association with air pollution in both rural and urban areas (1.29, CI: 1.27-1.31).



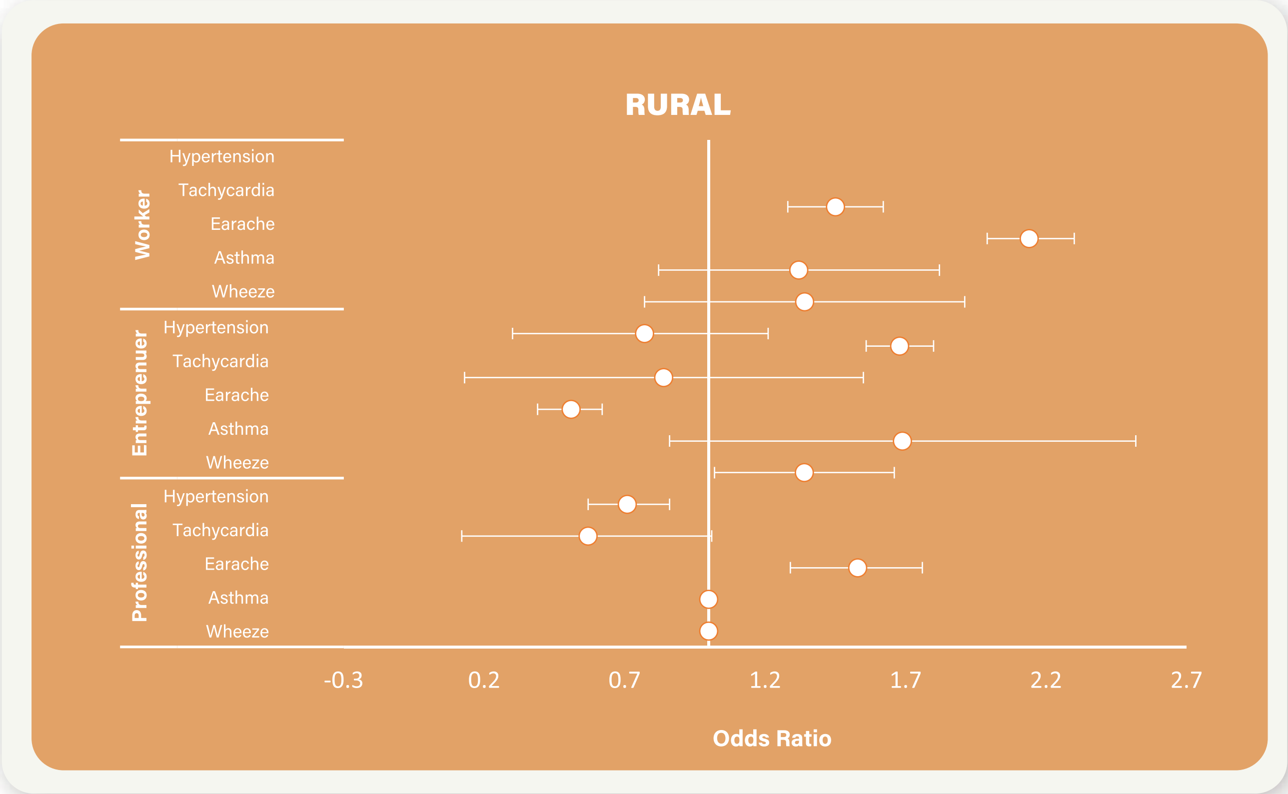


Figure 9: Distribution of odds ratios for respiratory and cardiovascular symptoms by occupation of the participants [Vertical line marks the OR=1]

Professionals and workers are exposed to air pollution emissions from vehicles, industries and power plants in urban regions, so health outcomes are more prevalent in them compared to entrepreneurs. In rural regions, workers and entrepreneurs are more exposed to indoor air pollution and emission from the industry; hence respiratory diseases are more developed in them (Ghosh et al., 2002). Duration and type of air pollution are keys to these health outcomes (Cori et al., 2020).

Socio-economic status (SES) and health response to air pollution

When air pollution exposure was analyzed in people with different SES categories in urban and rural regions, it was found that people with high and middle SES were more susceptible than low SES; whereas a higher health burden was observed in people in low and middle SES than high (Table 4). For short-term exposure, a significant association was found for breathlessness (1.27, CI: 0.89-1.64) in middle SES, followed by nasal congestion (1.18, CI: 1.08-1.28) in low SES in the urban region. In rural areas, a high association was found for runny nose (1.91, CI: 1.82-1.99) in low, followed by nasal congestion and breathlessness (1.23, CI: 1.14-1.32) in middle and sneezing (1.14, 1.07-1.21) in high SES.

For prolonged exposure to air pollution ($PM_{2.5}$), higher associations were found for tachycardia (1.63, CI: 0.96-2.3), wheeze (1.3, CI: 0.4-2.19), ear ache (1.27, CI: 0.52-2.02) and asthma (1.18, CI: 0.31-2.04) in high SES, followed by ear ache (1.46, CI: 0.78-2.12), hypertension (1.18, CI: 1.02-1.35) and tachycardia (1.16, CI: 0.99-1.34) in middle SES, whereas lower association was observed for ear ache (1.27, CI: 1.06-1.47) and asthma (1.16, CI: 0.99-1.32) in low SES population.

In case of rural regions, high associations were found in low SES for hypertension (1.66, CI: 1.5-1.82), tachycardia (1.45, CI: 1.27-1.64) and asthma (1.3, CI: 0.65-1.96), then for wheeze (1.75, CI: 0.8-2.7), ear ache (1.69, CI: 1.5-1.87) and hypertension (1.63, CI: 1.37-1.88) in middle and lower in tachycardia (1.74, CI: 0.68-2.79), wheeze (1.6, CI: 1.31-1.88) and hypertension (1.29, CI: 1.07-1.51) in high SES.

In both the regions, risks for COPD, LRI and diabetes were similar; but the risks were higher in the rural population. COPD was higher in rural (1.68, CI: 1.62-1.74) than in urban (1.62, CI: 1.6-1.64), similarly for LRI (1.46, CI: 1.44-1.48 for rural and 1.44, CI: 1.43-1.45 for urban) and diabetes having the lowest risk (1.29, CI: 1.27-1.31).

Table 4: Distribution of odds ratios by socio-economic status (SES) of the participants. Odds in 'red' are statistically less significant

SES	SYMPTOMS	ODDS RATIO (URBAN)	ODDS RATIO (RURAL)
High (19-25)	Wheeze	1.3 (0.4-2.19)	1.6 (1.31-1.88)
	Asthma	1.18 (0.31-2.04)	1
	Ear ache	1.27 (0.52-2.02)	1.06 (0.68-1.43)
	Tachycardia	1.63 (0.96-2.3)	1.74 (0.68-2.79)
	Hypertension	0.89 (0.83-0.96)	1.29 (1.07-1.51)
Middle (12-18)	Wheeze	1.07 (0.59-1.55)	1.75 (0.8-2.7)
	Asthma	1.08 (0.59-1.57)	1
	Ear ache	1.46 (0.78-2.12)	1.69 (1.5-1.87)
	Tachycardia	1.16 (0.99-1.34)	1.03 (0.83-1.23)
	Hypertension	1.18 (1.02-1.35)	1.63 (1.37-1.88)
Low (5-11)	Wheeze	1.12 (0.92-1.34)	1
	Asthma	1.16 (0.99-1.32)	1.3 (0.65-1.96)
	Ear ache	1.27 (1.06-1.47)	1.09 (0.42-1.75)
	Tachycardia	0.95 (0.85-1.05)	1.45 (27-1.64)
	Hypertension	1.13 (0.85-1.4)	1.66 (1.5-1.82)

The pattern for the degree of health burden was the opposite in urban and rural regions. SES is the combination of education, per-capita income and occupation, which act as effect modifiers in the development of health burden. Types of emission, socio-demographic factors and household type can be inferred from the knowledge of SES and these are different for the scenarios of urban and rural regions. Thus, the inverse pattern was observed in this analysis (Mukhopadhyay et al., 2009).

Outcome from Regression model

Health outcomes from the multivariate logistic regression model showed a significant ($p < 0.01$) and strong correlation with short and long-term ambient air pollution exposure (results are documented in Appendix). In the rural region, asthma showed the highest correlation coefficient (R^2 : 0.95) and hypertension showed the lowest association (R^2 : 0.78) for long-term and chest discomfort with the highest (R^2 : 0.95) and sore throat with the lowest (R^2 : 0.77) association for short-term exposure. Correlation coefficient was higher for male (R^2 : 0.93) than female (R^2 : 0.89) for long-term and also for short-term exposure (R^2 : 0.9 for male & R^2 : 0.86 for female). For the age categories, regression coefficients were higher for adult (R^2 : 0.88) than young and aged for long-term exposure, whereas for short-term exposure coefficients were similar for all aged people (R^2 : 0.84). Among the occupational categories, coefficients were highest for professionals (R^2 : 0.93) and entrepreneurs (R^2 : 0.92), followed by workers (R^2 : 0.89) for long-term exposure, as of age, regression coefficients were similar for all occupational categories (R^2 : 0.88) for short-term exposure. For socio-economic classes, coefficients were highest for middle SES (R^2 : 0.91) followed by low and high SES for long-term and for short-term exposure; coefficients were higher for the middle (R^2 : 0.88) and high (R^2 : 0.8) than low SES.

For urban regions result outcomes for the correlation coefficients were significant ($p < 0.01$), asthma showed the highest regression coefficient (R^2 : 0.95) and hypertension with the lowest (R^2 : 0.74) for long-term and chest discomfort with the highest (R^2 : 0.93) and sneezing showed the lowest (R^2 : 0.77) association for short-term exposure. The correlation of determination was higher for females (R^2 : 0.86) than males (R^2 : 0.82) for long-term and also for short-term exposure (R^2 : 0.88 for females & R^2 : 0.85 for males). For the age categories, regression coefficients were higher for adults (R^2 : 0.86) and aged (R^2 : 0.87) than young for long-term exposure, whereas for short-term exposure correlation coefficients were higher for aged people (R^2 : 0.87) than adult and young. Among the occupational categories, coefficients were highest for entrepreneurs (R^2 : 0.92), followed by workers (R^2 : 0.87) and professionals (R^2 : 0.8) for long-term exposure, as of age, coefficients were similar for all occupational categories (R^2 : 0.86) for short-term exposure. For socio-economic classes, coefficients were highest for high SES (R^2 : 0.89) followed by middle and low SES for long-term and similar trends were found for short-term exposure, coefficients were higher for high (R^2 : 0.89) and middle (R^2 : 0.85) than low SES.

Professionals and entrepreneurs are more exposed to outdoor air pollution comprised of vehicular emissions whereas workers are more prone to emissions from power plants and industries. In rural regions, both male and female are exposed to outdoor and indoor air pollution exposure whereas in urban regions, males are more exposed to outdoor air pollution and female are less exposed as most of the households contains clean fuels and chimneys. Since we have incorporated other socio-economic confounder variables in our model, we have obtained very strong and significant associations for most of the health outcomes.

LIMITATIONS OF THE STUDY

- Population-based cohort studies are susceptible to selection bias; differences in personal characteristics, differences in topography, meteorology, and time of survey as well as differences in pollution sources could lead to these biases (Morgenstern and Thomas, 1993; Elliott et al., 1995; Lash et al., 2009).
- As the analysis revealed, the number of respondents with respiratory symptoms was highest in air polluted areas which may be influenced by the concentration of low-income families in air polluted neighborhoods.
- During the survey, the exact geo-code (lat-long) was not recorded for each household; hence absolute exposure for every respondent can't be estimated. For simplicity in our analysis, we assumed that residents within every 1x1 km region of survey locations were exposed to similar $PM_{2.5}$ concentrations.
- During the survey, the sample size for different socio-demographic classes was not homogeneous. The numbers of adults and middle-income people were higher than others; this could lead to the 'sampling bias' to some extent.
- The effect of air pollution on co-morbid patients, who receive medical treatment, and the effect of air pollution on patients suffering from various health outcomes, but not taking medications, may be different (Delfino et al., 2008; Liu et al., 2009). However, we had no robust information on such 'undiagnosed' co-morbidity and had to rely on information obtained from questionnaires filled out by the patients.

CONCLUSIONS

As the present study indicates, long-term exposure to air pollution appears to have more detrimental effects on the urban population than rural. From the multivariate regression model, it is found that the development of URS and LRS prevalence is strongly associated with the level of air pollution exposure. In both urban and rural regions, women are more prone to develop respiratory disorders than men. URS symptoms are more observed in women in both regions, indicating indoor emissions could be a strong source of air pollution, especially in rural regions where women get are in direct contact with it. LRS symptoms were found to be have developed in men at to a greater extent, especially in urban regions, which indicates prolonged exposure to outdoor air pollution could be a reason for the development of complex respiratory symptoms. In terms of age categories, it was found that aged and young populations were more prone to air pollution exposure mostly in urban regions where the level of air pollution is higher. Workers and professionals who stay outdoors for a longer duration develop higher respiratory symptoms in both regions. The lower odds ratio was observed in entrepreneurs who mostly stayed inside their shops and stores and were less exposed to air pollution; especially the difference in odds was higher in urban regions compared to rural regions. This analysis has shown that COPD has a higher health burden than LRI and diabetes for prolonged exposure to air pollution, where the risk is higher in urban regions. The living arrangement, household type, marital status and area of residence were proved to be significant confounder variables for the exposure-response function. Both indoor and outdoor air pollution exposures and exposure disparity among various categories of people are strongly influenced by these parameters.

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