Air Quality and Human Health: A Comparative Analysis Of Urban and Rural Areas

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Abstract
Pollution has a major influence on public health, especially those related to respiratory and cardiovascular diseases. Pollution can be largely caused by industrial, traffic, or agricultural emissions, and this produces more in urban than in rural zones. The outcome of this study is to compare air quality and health outcomes in urban and rural areas. In this cross-sectional study, air quality is compared between New York City (urban) and Madhubani (rural). PM2.5, NOx, CO, and SO_2 were monitored, and health data from surveys on respiratory and cardiovascular symptoms were obtained. T-tests, chi-squared tests, and multivariate regression were statistically analyzed. PM2.5 and NOx concentrations were elevated in the urban zones than in the rural zones. Urban regions had higher rates of symptoms of respiratory as well as cardiovascular health. The exposure to these pollutants was also confirmed to lead to strong health outcomes through regression analysis. Pollution is higher in urban areas, and people are more at risk of developing health issues relating to respiratory and cardiovascular diseases. However, although polluted less, there are still risks from farm activities in rural areas. Urban emissions should be reduced, and rural agricultural pollutants should be addressed in policies.

Keywords: Air quality, urban health, rural health, air pollution, cardiovascular disease.

Aims And Background

The health problems caused by air pollution exposure are diverse and especially relate to respiratory and cardiovascular systems, and the quality of air is a major determinant of the overall health of the population[1]. In cities, the number of pollutants is generally greater because of traffic and industrial emissions, as well as human activities[2], and it is closely associated with respiratory and cardiovascular diseases and premature mortality[3]. The agricultural activities, biomass burning, and local sources have impacts on rural areas, though with less concentration of conventional pollutants than in other regions[4]. Industrialization and traffic are the most common causes of urban pollution[5], and agricultural activities and domestic heating form the major sources of rural pollution[6]. The effects of exposure on health are dependent on socioeconomic status, healthcare access and lifestyle[7].The bulk of the research has been done in an urban setting with scarce comparative research done in rural settings. Industrialization and transportation are prioritized in urban papers[8], whereas the rural ones concern agricultural pollution[9]. Nonetheless, there are still few direct comparisons, particularly in quickly developed regions[10].

The paper supposes that urban populations are at more risk, and the quality of air is worse, whereas rural citizens are also at risk due to agricultural emissions[3]. The results emphasize the necessity of specific policies, and urban interventions should be related to emission reduction[5], and the rural ones to agricultural pollution[6]. The purpose of the paper is both to evaluate the quality of air and health outcomes in various regions and to identify the inequalities by differences between environmental factors. It gives a quantitative and comparative measure of the contribution of these pollutants in the aerosols to the differences observed and evaluates the health effects of the respiratory and cardiovascular systems.

Experimental

Study Design

This study is designed as a cross-sectional study to test the difference in air quality and health results in an urban and rural environment. Since cross-sectional approach enables a brief duration of air pollution exposure and health impact related data to be contrasted on an environment-to-environment basis, it can be employed accordingly. The study design

provided a comprehensive evaluation of air quality measurements and health outcomes that would be achieved with less effort without involving longitudinal monitoring.

Sampling
The experiment involved two regions, the urban region with high industrialization, heavy traffic, and high energy consumption, and the rural one, which was agricultural, burned biomass, and low density. The setting was the city of New York, USA, with a population of above 8 million people and a high level of vehicular and industrial emissions. It was localized air pollution in Madhubani, Bihar, India where farming activities were practiced. The criteria used to select the populations were population density, industrialization level and accessibility of environmental data.

Data Collection
The real-time PM2.5, NOx, CO, and SO_2 air quality data were gathered in the real-time monitoring stations located in fixed sites in high-traffic urban regions and in rural agricultural areas. Health information on respiratory and cardiovascular symptoms was received with the help of surveys and secondary data with the local hospitals, such as admission reports and mortality rates due to air pollution.

Instruments
The stationary sensors and personal monitoring devices were used to measure exposure levels. Structured questionnaires that were administered to age, gender, and occupation groups were used to determine the health outcomes that included symptoms and disease history. Local health records were used to obtain additional data on hospital admissions and respiratory and cardiovascular diagnosis. The calibration of all instruments to standard guidelines was done to provide accuracy and reliability.

Statistical Analysis
Descriptive statistics summarized the concentrations of the pollutants on the air quality and health effects of the pollutants in terms of means and standard deviations. A t-test was used to compare the mean levels of pollutants in the air environments between urban and rural environments and a chi-squared test was used to compare air quality exposure to respiratory or cardiovascular disease occurrence when potential confounders (i.e., age, gender, socioeconomic status) are put into consideration. This was followed by multivariate regression analysis to assess the relationship between the pollutant exposure and the health problems and the significance level of $p < 0.05$.

Ethical Considerations
Ethical standards for studies involving human subjects were adhered to in this investigation. All participants involved in the health surveys were provided informed consent and assurances of confidentiality and anonymity. Data collection was sought from the relevant institutional review board (IRB) for ethical approval.

Results And Discussion

Descriptive Statistics And Air Quality Analysis
The main pollutants (PM2.5, NOx, CO, SO_2) were compared based on the information on urban and rural locations. The industrial and vehicular emissions in the urban areas increased PM2.5 and NOx. The PM 2.5 was 78 ug/m 3 in the urban and 28 ug/m 3 in the rural regions (Table 1). The concentrations of PM2.5 (78 ± 15 µg/m 3), NOx (42± 8 ppb), CO (1.2± 0.3 µg/m 3) and SO2 (0.8± 0.2 µg/m 3) were significantly larger in urban areas than in the rural environment ($p < 0.05$). There were evident effects of air quality disparities between urban and rural settings on health outcomes. Cities contained much more of all types of pollution, and the concentration of PM 2.5 was about three times greater (78 vs. 28 µg/m 3). These results are consistent with the findings of the earlier research that associates dense traffic and industrial activity with the rise in pollution. There was also high emission of NOx in urban areas because of vehicular and industrial emissions. The pollution also impacted rural locations, although at lower rates, even though in this case, it was caused by agricultural activities (biomass burning and crop dusting)[11,12]. Research has shown that even in rural regions where the countryside is usually associated with cleanliness, there is still a pollution problem related to the agricultural factor[9].

Table 1: Air Quality Data Comparison Between Urban and Rural Areas

Pollutant	Urban Area (µg/m³/ppb)	Rural Area (µg/m³/ppb)	p-value
PM2.5	78 ± 15	28 ± 7	<0.001
NOx	42 ± 8	18 ± 5	<0.001
CO	1.2 ± 0.3	0.9 ± 0.2	0.015
SO2	0.8 ± 0.2	0.4 ± 0.1	0.020

NOx levels in the urban area were 42 ppb and 18 ppb in the rural area. Urban levels were higher for CO and SO2 concentrations (Fig.1), but the differences were more moderate.

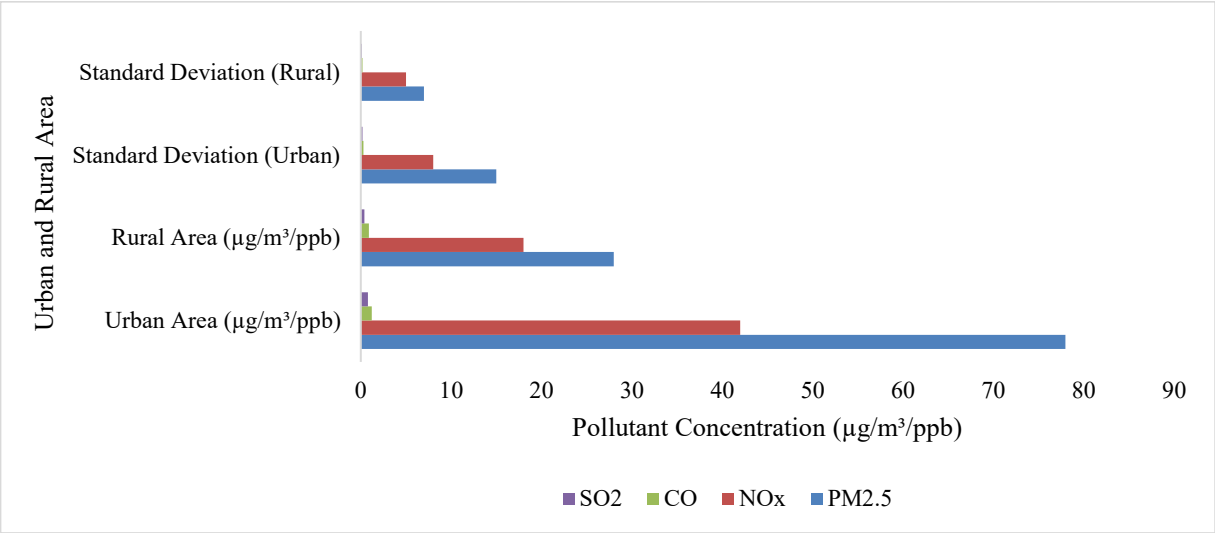

Fig.1. Comparison of Pollutant Concentrations in Urban and Rural Areas

Figure 1 represents the difference between urban and rural regions in terms of the average level of pollutants (PM2.5, NOx, CO, and SO2). The most significant variations in PM 2.5 and NOx are between the urban and the rest of the area, in all the pollutants measured the urban area always records higher values of pollutants. Error bars in each of the pollutants are given by standard deviations of each pollutant, as an indication of the degree of variation of the pollutant around the average in each area. The statistics indicate that urban areas are polluted, which is attributed to motor and industrial emissions.

Health Outcomes And Interpretation

There was an increased prevalence of respiratory and cardiovascular symptoms on the health data of urban and rural residents. Table 2 shows that 58 percent of the urban dwellers reported respiratory symptoms including cough and wheezing, as compared to 31 percent of the rural dwellers, with the difference being statistically significant ($p < 0.001$). In the same way, it was found that cardiovascular conditions were reported in 35 percent of residents of urban areas and 20 percent of rural areas ($p = 0.004$), which indicated a higher health burden in urban populations. These results are consistent with the published research associating the low quality of air with respiratory diseases[13], as the urban population has an increased level of such COVID-related symptoms as coughing, wheezing, and shortness of breath. CVDs such as hypertension, heart disease are also more common in the urban environment, presumably because of the long-term exposure to high amounts of pollutants.

Exposure to pollutants like PM2.5 and NOx during a long period of time was linked to cardiovascular morbidity and mortality[14]. Even though agricultural pollution exposes rural people to less conventional urban pollutants, they are still at significant risk of agricultural pollution. Though the respiratory symptoms were less reported than in cities, local sources of conditions associated with biomass burning and other causes are relevant[6]. These results underscore the need to take into account the entire sources of pollution, in the process of assessing the quality of air and the level of health in the urban and rural contexts.

Table 2. Prevalence of Respiratory and Cardiovascular Symptoms in Urban and Rural Areas

Health Outcome	Urban Area (%)	Rural Area (%)	p-value
Respiratory Symptoms	58	31	<0.001
Cardiovascular Conditions	35	20	0.004

STATISTICAL ANALYSIS AND DISCUSSION

Variations in air quality between urban and rural locations were statistically significant, with all pollutant levels higher in urban areas ($p < 0.001$ for PM2.5 and NOx; CO $p = 0.015$; SO2 $p = 0.020$). Chi-squared tests showed a strong correlation between air pollution exposure and respiratory and cardiovascular conditions, with respiratory symptoms 1.9 times and cardiovascular conditions 1.75 times more likely in urban populations. Multivariate regression analysis showed a strong association between PM2.5 and NOx exposure and increased risk of respiratory symptoms ($\beta = 0.45$, $p < 0.001$) and cardiovascular conditions ($\beta = 0.38$, $p = 0.004$), even after controlling for other factors. Table 3 confirms significant positive coefficients for both pollutants. Respiratory symptoms were associated with PM2.5 ($\beta = 0.45$, $p < 0.001$) and NOx ($\beta = 0.37$, $p = 0.002$), while cardiovascular conditions were linked to PM2.5 ($\beta = 0.38$, $p = 0.004$) and NOx ($\beta = 0.33$, $p = 0.009$). The relationship between PM2.5 exposure and respiratory symptoms is illustrated in Figure 2.

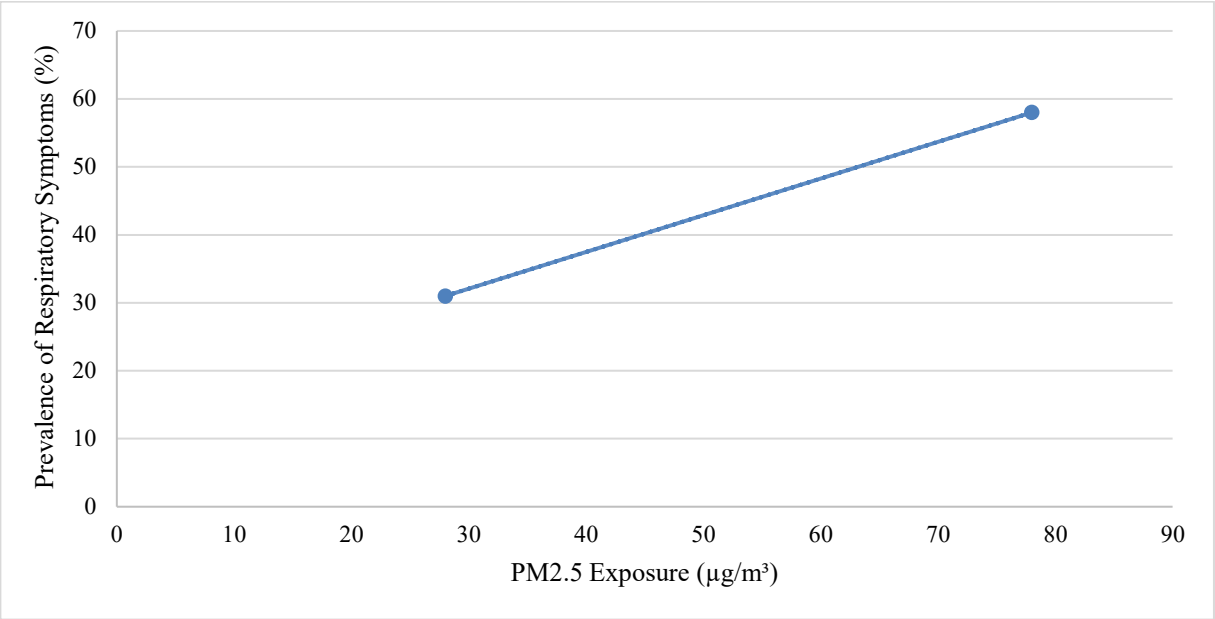

Fig. 2. Regression Analysis Results for Respiratory Symptoms

In urban areas with greater PM2.5 concentrations (78 µg/m³), the prevalence of respiratory symptoms is higher (58%) than in rural areas (28 µg/m³), which have lower PM2.5 concentrations (31%). The PM2.5 levels are positively associated with respiratory symptoms from the regression trend line, with both areas causing statistically significant results (Urban: beta = 0.45, $p < 0.001$; Rural: $\beta = 0.37$, $p = 0.002$).

Table 3: Multivariate Regression Analysis of Air Pollution and Health Outcomes

Health Outcome	β (Coefficient)	p-value
Respiratory Symptoms (PM2.5)	0.45	<0.001
Respiratory Symptoms (NOx)	0.37	0.002
Cardiovascular Conditions (PM2.5)	0.38	0.004
Cardiovascular Conditions (NOx)	0.33	0.009

Broader Interpretation And Policy Implications

The results indicate that urbanization is a major factor that exacerbates the quality of air and health risks. Population density, transportation, and industrial activities are also key contributors of air pollution, both indoor and outdoor, in urban areas[15]. The rapid urbanization boosts concentration of PM2.5, NOx, and CO, which negatively impacts on the health of people, particularly the vulnerable groups. PM2.5 and NOx of high concentrations are associated with respiratory diseases, heart diseases, and early death[16]. Coronary heart disease, asthma, and COPD are also significantly exposed to the risk of urban air pollution[17]. Exposure is also enhanced by socioeconomic differences because low-income populations have a stronger exposure to pollution and healthcare access[18,10]. Socioeconomic status, lifestyle, and healthcare access are also confounding factors[19]. People living close to industrial and traffic locations have a higher exposure and health care barrier[7], and rural citizens can be underrepresented because of the lack of healthcare[20]. There are significant policy implications of the findings. The urban plans must be devoted to the decrease of emissions and encouragement of cleaner energy [21,22]. Exposure can be alleviated through the provisions of urban planning such as green spaces. The problem of pollution caused by agricultural activities and biomass burning in the rural areas should be addressed. Air quality and health outcomes in both settings can be improved by making healthcare services more accessible, raising awareness, and combining policies.

Limitations

This study has several limitations. The cross-sectional nature of the study permits the significant conclusion of air pollution to health conditions to be constrained and the long-term effects should be researched by the application of longitudinal studies. Measurement of personal exposure variation, which was not undertaken, would be necessary in the inspection of the personal exposure variation, i.e. the indoor air quality and the individual exposure. Possible bias on survey-based health data Recall bias: The survey-based health data may have bias on the recall of the survey-based data. Nevertheless, the confounding factors like socioeconomic status, lifestyle factors that affect the exposure and the health outcomes were also not incorporated in the study.

future directions

Future research on air pollution exposure is important to study because long-term exposure to health is not well understood both in rural and urban areas. Such individual exposure levels will be captured by introducing personal air quality

monitoring devices, which will give much more accurate data than a fixed monitoring station will be able to capture. Moreover, another study should be conducted to ascertain the connection between air pollution and health outcome based on the socioeconomic status or lifestyle factors other than the effect of access to healthcare. The study could be extended to other areas, including the developing nations, to get a more holistic concept of the air quality issue around the whole world. Moreover, those studies that involve interventions on the efficiency of policy actions and health intrusions to lessen air pollution and enhance populace health would be an excellent aide to policy-makers trying to keep the effects of health problems created by air pollution to the bare minimum.

Conclusions

In this paper, there is a notable air quality and a health disparity in urban and rural areas regarding the subject of population health. With a high level of traffic, energy usage, and industry emissions, urban settings have high concentrations of pollutants like PM2.5 and NOx and, as a result, respiratory and cardiovascular diseases are more prevalent. Such results are supported by the previous studies that associated air pollution in the city with the chronic diseases such as asthma and COPD. The results of multivariate regression analysis also confirm the high level of interdependence between the adverse health effects and exposure to pollutants among urban residents. Even though the rural areas have less conventional urban pollutants the areas are not devoid of environmental health hazards. Biomass burning and crop dusting, agricultural activities, are important contributors of air pollution and have significant respiratory symptoms. These results highlight the importance of the fact that the issue of rural air pollution, which has been underestimated, is also of serious influence on the public health. The article highlights the importance of specific policy interventions in either of the environments. The strategy in urban areas should aim at setting an emission target that is lower and encouragement of transportation methods as well as the use of cleaner energy sources. At the same time, agricultural pollution should be dealt with by rural policies. Such measures can be used to improve the quality of the air and decrease the total workload of the pollution-induced diseases among the urban and rural population.

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