Environmental Equity and Vulnerability to Air Pollution: Evidence from Delhi, India

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ABSTRACT

This paper tries to find evidence of environmental inequity. In order to find out the relationship between socio-economic characteristics and air pollution exposure, the paper first computes a household-specific air pollution exposure index for 347 households around seven pollution monitoring stations in Delhi, India. The index is then used in a multivariate regression to look into the environmental equity aspect. The analysis yields that the economically backward communities are the most affected by the exposure to air pollution. However, the study could not find any evidence of environmental inequity due to religion and the evidence was weak for the communities, which are socially backward. Education facilitates defense against the exposure, when it crosses a threshold level. The separate analysis of residential and industrial areas suggest that exposure to air pollution is indeed dependent, though not systematically, on the location of residence besides their socio-economic status. While the Delhi government in the recent past has taken up several steps to tackle the menace of air pollution, what is needed is an effective air pollution control policy keeping in view the distributional aspects of the air pollution problem.

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1. INTRODUCTION

Widespread evidence suggests that human vulnerability to environmental shocks that causes widespread mortality and morbidity is distributed unevenly. Not only is the impact disproportionate, but the ability of people and societies to adjust to and deal with such shocks is also quite skewed. On account of lower levels of social, economic and infrastructure amenities, compounded sometimes by the State's apathy, people in developing countries like India are faced with lower coping capacities, and therefore, they experience an uneven burden of the impact of natural calamities and also pollution.[1] This is also exemplified by the Global Environment Outlook report of United Nations Environment Programme (UNEP, 2002), which states, 'human exposure to environmental threats is unevenly distributed'. In the context of examining such discrepancies, the terms 'environmental equity' and 'environmental justice' are sometimes used interchangeably. However, according to Lavelle (1994)[2] environmental equity implies an equal sharing of risk burdens but not necessarily a reduction in the total burden of pollution. Cutter (1995)[3] on the other hand, argues that environmental justice signifies much more, as it includes remedial action to correct an injustice meted out to a specific subgroup of society.

Exposure to air pollution is a major environmental health problem affecting the developing and the developed countries alike. According to WHO estimates, 4-8 per cent of deaths occurring in the world are related to air pollution, whereas a 2005 estimate from WHO indicates that air pollution in major Southeast Asian and Chinese cities ranks among the worst in the world and contributes to the deaths of about 500,000 people annually.[4] People are concerned about air pollution because it affects health and damages property, with the health damage being of primary concern. Some pollutants are more dangerous to humans than others. Despite pollution control policies, the air quality has been threatened to alarming levels in several cities throughout the world even as nearly half of the world's population (47 per cent) lives in urban areas, a figure which is expected to grow by 2 per cent per year during 2000-15 (United Nations Population Division, 2001). According to an estimate by the World Resources Institute (2000), nearly 1.4 billion urban residents in the world breathe air exceeding the WHO air quality guidelines.

It is well established that air quality in different cities may vary spatially and also that pollution in a given city varies temporally, but what is more important is the distribution of air quality within a large city. The air quality in a city could have a highly skewed distribution affecting some people more adversely than the others (Kruvant, 1975). As mentioned, knowing this distribution is essential, if environmental justice is to be bestowed.

Keeping this in view, this paper investigates which are the most likely households, belonging to various socio-economic traits, to be affected by the exposure to air pollution in a developing country. This is carried out by constructing a household exposure index and then finding the relation between this

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[1] The Bhopal gas tragedy in India in 1984, tsunami in 2004 in South Asia and Southeast Asia or the earthquake in Kashmir and Pakistan in 2005 are testimony to this.

[2] As referred in Brainard *et al*. (2004: 1).

[3] Same as above.

[4] Among various pollutants, SPM is considered to be the most sinister in terms of its impact on morbidity and mortality. Numerous epidemiological studies conducted, mainly in the US and other developed countries, since the early 1970s have estimated dose-response parameters for particulates measured by either total suspended particulates (TSP) or of the particulate spectrum defined by particle diameter (e.g., PM_{10}) or the chemical composition (e.g., sulphates SO_4^{2-}). With few exceptions, the studies have found that after controlling for other factors, mortality rates are lower in areas with lower ambient particulate concentrations (see Vincent and Tan, 1997 for a review of this literature).

exposure index with the socio-economic characteristics in the national capital territory of Delhi, India. The study becomes important because Delhi exhibits very high air pollution levels coupled with an ever-bursting population. Thus the study has two objectives: to (i) define and construct a household specific index of exposure; and (ii) examine the cross-sectional relationship between exposure and various socio-economic and other characteristics of the population for the capital city of India, Delhi. The different socio-economic characteristics include income, caste, education, sex, etc.

Delhi is the third most populated city in India with 13.8 million inhabitants spread over 1483 sq. km. The population density has increased in 10 years from 6352 in 1991 to nearly 9500 in 2000. Delhi's per-capita income is more than twice the national average. Compared to a national per-capita income of INR 10,254, it had a per-capita income of INR 24,450 in 2000-2001 at constant prices (Economic Survey of Delhi, 2001-02). Its length of 51.9 km. and width of 48.5 km. gives it a circular structure. The transportation network in Delhi is predominantly road based with 1,284 km. of roads per 100 sq. km. The past two decades have witnessed high industrialization and urbanization resulting in a rise in per-capita income by 60 per cent since 1993-1994 and corresponding vehicular growth. Its urban area has quadrupled from 182 sq. km. in 1970s to more than 750 sq. km. in 1999 with the number of industrial units rising from 26,000 in 1971 to 137,000 in 1999. Apart from vehicles and industrial units, the three thermal power stations also contribute to air pollution in Delhi (*ibid.*).

Air pollution is one of the major environmental problems faced by Delhi today. Despite effective implementation of CNG, Delhi is still one of the most polluted cities of Asia and ranks fourth in the world.[5] Rapid urbanization and the consequent increase in the number of vehicles have contributed significantly to the increase in combustion of petroleum products, and hence, pollution. Petroleum consumption has increased by almost 400 per cent in the last two decades. Vehicular pollution contributes 67 per cent of the total air pollution load in Delhi while industries and coal based thermal power plants contribute about 25 per cent. Earlier estimates indicate that about 9,859 people die prematurely every year in Delhi due to bad quality of air (CSE, 1997) and incidence of respiratory diseases in Delhi is 12 times the national average with 30 per cent of Delhi's population suffering from respiratory disorders.

The remaining paper is organized as follows. Section 2 reviews the relevant literature on the relationship between air pollution and socio-economic traits. Section 3 constructs a household specific exposure index for the population of Delhi, while Section 4 formulates the econometric model and explains the data used in the study. Section 5 reports the result of the econometric analysis. The paper concludes with Section 6.

2. EXPOSURE AND SOCIO-ECONOMIC TRAITS

Evidences from Developed Countries

There have been many studies on the linkage between exposure to air pollution and socio-economic traits but especially in the developed countries. In one of the earliest studies, Freeman (1972) used the 1960 Census data for Kansas City, Washington DC, and St. Louis, and concluded that Blacks and low income persons faced the highest exposure to both sulphur dioxide (SO_2) and particulates. In another study, Zupan (1973) found a considerable positive correlation between ambient concentrations of SO_2 and particulates, and the percentage of low-income households in New York City zip code. Kruvant (1975) analysed the exposure to non-point source emissions of carbon monoxide (CO) and hydrocarbons (HC) in the Washington DC area and discovered that low incomes, low rents, low proportions of professional and managerial workers, and high proportions of Black residents characterized the most highly polluted zones. Asch and Joseph (1978) studied 284 cities and 23 states and found a significant positive

[5] A recent study by Kathuria (2005) has found that after implementation of CNG, though pollutants like SPM and RSPM have stabilized, the NOx has increased and is now above the stipulated standards at one of the most busiest intersections (i.e., Bahadur Shah Zafar Marg/ITO).

relationship between exposure to particulates and more densely populated cities with lower incomes, lower educational levels, and higher proportions of nonwhite residents.

Brajer and Hall (1992), in their study of the South Coast Air Basin of California found evidence of higher exposure to ozone and particulates among low-income, and ethnic groups, mainly Black and Hispanic residents. The study also finds that population density is negatively related to exposure, whereas high-income group shows a strong negative association with income. Harrison and Rubinfeld (1978), based on their study for the Boston metropolitan area, concluded that the physical benefits of abatement accrue more to poor than to rich. In an interesting study, taking account of both costs and benefits, Gianessi *et al.* (1979) argued that the net benefits of uniform standards seem to imply a redistribution of welfare toward a minority who are largely nonwhite residents of urban areas. Asch and Joseph's (1978) study also concludes that the impact of uniform standards on changes in exposure to particulates over the period 1972-74 was distributed progressively.

Most of the previous studies until early 1990s used ambient concentration as an indication of pollution. In a significant departure, Brooks and Sethi (1997) computed an index based on toxicity of 150 most significant air toxics rather than ambient concentrations for the entire United States. The study then looked into whether exposure varies across various socio-economic characteristics including income, race, educational attainment, housing tenure, and the propensity of communities to engage in collective action. The study revealed greater exposure in black communities even after controlling for a variety of variables. Another important variable - Voter turnout – a reflection of collective action, is found to affect exposure, whereas local socio-economic conditions are found to influence changes in exposure levels.

Of late, some recent studies have reinforced the results. Villeneuve *et al.* (2003) evaluated the relationship between daily levels of particulate and gaseous phase pollutants and mortality for different classes of income. The percent change in all-cause, cardiovascular, respiratory, and cancer daily mortality was calculated in relation to short-term changes in levels of a number of particulate[6] ($PM_{2.5}$, $PM_{10\text{-}2.5}$, total suspended particle (TSP) co-efficient of haze, PM_{10}, and SO_4) and gaseous (O_3, CO, SO_2, NO_2) pollutants. The study finds increased risk of all-cause and cardiovascular mortality at lower levels of income. Similarly, an inventory of pollution releases in England shows that 90 per cent of polluting factories in London are in areas with below-average income (FOE-UK, 1999),[7] thereby affecting the population disproportionately.

Jerrett *et al.* (2004) in their study of Hamilton city, Canada, found that increased mortality was associated with air pollution exposure in intra-urban zones with lower socioeconomic characteristics. Low educational attainment and high manufacturing employment in the zones were significantly and positively related with the acute mortality effects of air pollution exposure. Davis (1981) found that Blacks faced racial discrimination in terms of job segmentation and exposure to work place hazards. Likewise, Robinson (1989) documents that people of color were more likely to be exposed to occupational hazards and suffer work-related illnesses than whites.

Of late, efforts have been put in to see the extent of inequalities in exposure to other mediums like noise, waste treatment and disposal, etc. See for example, Brainard *et al*. (2004) for evidence of how the socio-economic and ethnic characteristics influence the noise exposure in the city of Birmingham in the English midlands. The study finds evidence, though somewhat weak, of an association between noise exposure and ethnicity. Similarly, Pastor *et al*. (2001) examine the siting versus minority-move-in hypothesis using

[6] The SPM can be characterized in several ways: (i) TSP is the fraction with particle diameters <50–100 μm; (ii) PM_{10} or RPM: inhalable particles, diameter <10 μm; (iii) thoracic particles: approximately equal PM_{10}; (iv) $PM_{2.5}$: fine fraction, diameter <2.5 μm; and (v) black smoke: measure of blackness gives relative value for the soot content of the sample (Kathuria, 2002).

[7] Infact, this is not unusual. Even if industries are set up in affluent areas, sorting takes place, resulting in richer communities moving out and communities dependent on these industries for employment either move in or remain there.

longitudinal data on the siting and location of toxic storage and disposal facilities (TSDFs) in the Los Angeles County from 1970 to 1990. The results indicate that the proportion of minority residents living within a 1-mile radius of a TSDF increased from 9 per cent in 1970 to over 20 per cent in 1990, whereas the increase for White residents was less, from 5 per cent to nearly 8 per cent. And the areas receiving TSDFs between 1960 and 1990 had a higher proportion of residents of color, were poorer and more blue-collar, had lower initial home values and rents, and had significantly fewer homeowners.

Evidence from Developing and Transition Countries

Recent efforts of researchers have also been directed to see the impact in developing and middle-income countries. In a study of six regions of Sao Paulo, Brazil, Martins *et al.* (2004) suggested that socio-economic deprivation represents an effect modifier of the association between air pollution and respiratory deaths in elderly people for an increase of 10 $\mu g/m^3$. The relationship is established using generalized linear Poisson regression models for the daily number of elderly respiratory deaths after controlling for long term trend, weather, and day of the week, from January 1997 to December 1999. The study finds a negative effect of PM_{10} on both percentage of people with college education and high family income, and positive association with the percentage of people living in slums. Based on the results, the study concludes that poverty represents an important risk factor that should be taken into account when determining the health consequences of environmental contamination. In another study on air pollution and income, Wheeler *et al.* (2000) has found that low-income families are more likely to live in polluted areas.

Evidence from India

In India, no study exists looking into the environmental justice aspect. The studies in India have been confined to only quantifying the health damages from air pollution. The recent study by Murty *et al.* (2003) finds that the annual damages from the morbidity effects of air pollution in Delhi is of the order of Rs. 4896.6 million. In an earlier study, Cropper *et al.* (1997) established that a reduction in air pollution levels in Delhi would result in 3,430 avoided deaths.

As can be seen, these studies talk about the human populations as a whole but are silent on the distribution aspects of the pollution with respect to the socio-economic characteristics of the concerned population. Therefore the present study fills the gap. In order to establish the relationship, the present study computes an exposure index for a household. This index is then used to find out the nature of the relationship with the socio-economic characteristics of the residents of Delhi.

3. INDEX OF EXPOSURE

In order to find how people are exposed to air pollution, an ideal index of exposure, should be sensitive to: (i) the distance of the exposed person from the source, and (ii) the time spent by the exposed person under the exposure. Finding distance of the exposed person from the source requires a modeling exercise, whereas finding the time spent by the exposed person requires the knowledge of person's activities during the day. Unfortunately, no study exists that tries to compute an exposure index at the household level. Studies like Brooks and Sethi (1997) have computed an index at a region level where it is the pollution at a region or zip code level rather than at the household level. The present study assumes that in and around a region / pollution monitoring station (PMS) each individual is exposed equally, but the average household exposure varies depending upon the number of household members and their age distribution.

The pollution monitoring body in Delhi, the Central Pollution Control Board (CPCB) is measuring only three major pollutants – SPM, SO_2 and NOx – at seven different locations.[8] The exposure index for the households is computed at these seven locations only. The pollution profile of Delhi indicates that among the three major pollutants, it is SPM only that exceeds the stipulated standards. The data shows that from 1999 to 2003, SPM varied from 430 $\mu g/m^3$ to 496 $\mu g/m^3$ in ITO PMS, whereas the value of SO_2 and NOx ranged close to 10 and 72 $\mu g/m^3$, respectively against the standard of 80 $\mu g/m^3$.[9] Thus, the index is computed for SPM only.

Household Air Pollution Exposure Index

This subsection explains the construction of the household specific exposure index. The area specific ambient levels of SPM in $\mu g/m^3$ are used to get the household air pollution index for every PMS by using the data collected through a primary survey on the age profile of a household in that particular area. For every household, different exposure time is assumed for different category of people. The assumption of different time is because even if exposed for the same number of hours the impact would be more on older people and children than for the adults. It is assumed that an adult male and female are exposed daily for 5 hours to the pollution, followed by an older female for 6 hours. This is followed by children and older male, who are assumed to be exposed for 8 and 9 hours, respectively[10] during a day.

The household exposure index can be computed as:

$$\text{HHXij} = \text{Xj}\,\frac{(\text{Nam} * \text{Tam} + \text{Naf} * \text{Taf} + \text{Nom} * \text{Tom} + \text{Nof} * \text{Tof} + \text{Nc} * \text{Tc})}{24 * \text{hh size}}$$

Where, j = 1,2…7 (seven PMSs) and i = number of sample households in each of these PMSs. X_j is the SPM concentration in $\mu g/m^3$ for the PMS 'j', Tam, Taf, Tom, Tof and Tc denote the exposure time in hours for adult males, adult females, old males, old females and children of a particular household.[11] Nam, Naf, Nom, Nof and Nc are the number of males (adult and old), females (adult and old) and children, respectively in the household. Looked at closely, the exposure index suggests that categories like children and older people, irrespective of being exposed for the same number of hours, would be affected to a greater extent due to age induced vulnerability.

Since the index yields a distinct level of exposure for each household in a particular PMS, these exposures have been combined with the socio-economic data, collected through the primary survey to see the relevance of environmental equity in the Indian context.

[8] Of late the CPCB has started monitoring RSPM also, but only at a few PMSs. Since RSPM data is not available for all the PMSs, the present study concentrates only on these three pollutants. The next section discusses in brief, the location of these PMSs.

[9] Refer Kathuria (2002, 2004) for an indication of the daily pollution profile of these three parameters at the busiest intersection in Delhi before and after introduction of CNG.

[10] Since the literature is virtually silent on the computation of a household specific exposure index, the robustness of the results are verified by constructing the exposure index alternatively by assuming different exposure hours for each age category of people.

[11] It can be seen that only adult members are distinguished by gender. Children have similar activities, such as going to school, playing outdoor etc., therefore the distinction on the basis of gender becomes irrelevant.

Determinants of Exposure

The literature suggests that the disproportionate exposure of pollution is primarily due to the socio-economic and demographic[12] characteristics of few communities. Thus, a model for the household air pollution exposure would be:

$HHX_{ij} = f(\text{Socio-economic\_characteristics}_{ij}, \text{Demographic\_Characteristics}_{ij})$,
where the subscript *i* and *j* refers to the i^{th} household in j^{th} PMS.

The socio-economic characteristics of a household consists of its income, education, etc; whereas caste, sex, proportion of older people and children, gender balance in the household fall under demographic characteristics of the household. The literature review indicates that the household exposure to air pollution depends on Income, Education, Caste (whether low or high caste), Religion (whether belong to majority or minority group). Similarly, a household with a larger proportion of females and larger proportion of more vulnerable members (i.e., the old and children) may be affected more given the same exposure hours. A house having a larger number of active outdoor members will be exposed more to pollution. Lastly, a household in a rented house may not resort to more defensive expenditure, if it involves some capital expenses, thereby increasing its vulnerability to pollution. Assuming a linear relationship of these variables with the exposure, the model to be estimated would be:

$$\ln HHX_{ij} = \alpha_1 + \beta_1 Inc_{ij} + \beta_2 Education_{ij} + \beta_3 Caste_{ij} + \beta_4 Religion_{ij} + \beta_5 Prop\_Fem_{ij} + \beta_6 prop\_Chil\_Old_{ij} + \beta_7 Outdoor\_prop_{ij} + \beta_8 Own\_house_{ij} + \mu_{ij},$$

where the subscript *j* refers to the PMS, μ_{ij} is the error term associated with PMS *j*, and the x_i are observations of the explanatory variables.

The log-linear form of model has been used to make the data approximately normally distributed because of the skewed distribution of some of the variables. Also, the log-linear formulations can take care of the problems of unequal variation and outliers. Moreover, it is easier to interpret the regression coefficients meaningfully in terms of growth in the dependent variable where a change of 1 per cent in the explanatory variable x_i corresponds to a percentage change in the dependent variable.

DATA AND VARIABLES

This section deals with the sources and characteristics of data used in the study. The primary data set, as obtained through primary field survey, includes information on various socio-economic and demographic variables. The data on air pollutants is collected from the secondary sources.

Location of PMS and Households

Primary data is collected using a questionnaire from 350 households within the vicinity of the pollution monitoring stations (PMSs). There are seven functioning air PMSs in Delhi, viz. Ashok Vihar, ITO, JanakPuri, Nizamuddin, Shahdara, Shahzada Bagh and Siri Fort. CPCB has categorized these stations as residential or industrial. Shahzada Bagh and Shahdara are designated as the industrial areas, whereas ITO, Nizamuddin, Siri Fort, JanakPuri and Ashok Vihar are considered as the residential areas. These PMSs are distributed across almost all the geographical locations of Delhi viz. North, North-West, South, West, Central and East Delhi (Figure 1).

The data on a sample of 350 households is collected with 50 households from each of the seven PMSs. Three questionnaires had to be rejected due to incomplete information, thereby reducing the final sample

[12] Some of the studies have also tried to see the role of political variables (see for example, Brooks and Sethi, 1997 in the case of US). Since the focus of present study is only one city i.e., Delhi – the voting pattern may not vary much, thereby finding the relevance of the political variable will not have much of an impact on exposure. If the analysis is carried out over a cross-section of cities having different political structures, the variable may have an influence.

to 347. The samples are drawn from the households within a 1.5 km. radius from each of the seven PMSs.[13] The target sample population is stratified into higher income (rich), middle-income and very low-income groups (slums) and then households are randomly selected. In order to avoid any bias and to extract correct information, a one-day training session was conducted for the interviewers. The household survey was carried out in the months of July and August 2003. The questionnaire elicited information regarding the respondents' household, including income, education, caste, type of house ownership, family size, nature of occupation, place of occupation, sex, and voters participation in voting, etc.[14]

Figure 1: Location Map of the Seven Pollution Monitoring Stations in Delhi

Construction of Variables

In order to see, the relevance of environmental equity in the present case, one has to find out whether exposure differs across high and low castes and/or community from a particular religion are more affected. However, the exposure needs to be controlled by a number of factors affecting the lifestyle. These include the income, proportion of the people working outside, education, composition of household, etc.

Caste (Caste): In India, caste is an important determinant of progression in society. Most of the menial works like garbage collection, vegetable vending, hair cutting etc. is often carried out by people from the lower caste. Not only are people of lower caste engaged more in outdoor activities, they also stay in somewhat cramped localities, thereby increasing their exposure. The present study uses a dummy variable taking on the value of 1 for lower caste and 0 for other castes. The lower caste households

[13] The choice of 1.5 km. is not arbitrary. Since these sites are either residential or industrial, topology plays an important role in dispersion of pollutants and hence exposure. In the present case, the dispersion and the exposure may not be beyond 1.5 km. unless the wind speed is very high. Given Delhi's location, barring few days in summer, the wind speed is not very high in Delhi.

[14] The detailed questionnaire is available from the authors on request.

represent scheduled castes (SC) and scheduled tribe (ST) households only. It needs to be stated that as compared to other developed countries, sorting in India is primarily based on caste (lower or upper) and religion. Thus, these categories may be affected by pollution disproportionately.

Religion (Religion): Along with caste, religion also indicates the progressive structure of Indian society. Though there is no discrimination in jobs based on religion, but the social structure indicates that some of the minorities are engaged in particular kinds of low-skilled and less-paid unorganized sector jobs, which may have a detrimental impact on their exposure levels. The present study uses a dummy variable taking on the value of 1 for majority religion (i.e., Hindu) and 0 for minority religion (Muslim, Sikh, Christian).[15]

Income (Income) (Rs. Lakhs): Income represents the economic vulnerability. A rich household is less likely to be exposed to air pollution, as the members may be incurring defensive expenditure or carrying out jobs with less pollution exposure. The present study measures Income as the gross annual household income earned from all the sources as measured in Rs. lakhs per annum.

Other controlling variables

Education (Education) (in years): A more educated household despite staying in a polluted locality can be less exposed as it may resort to defensive expenditure. This variable is constructed by taking the sum of the years of education of the first five adult members of the family and then taking the average.

Type of house ownership (Owned_house): Inequities in the housing market leading to differential residential environmental exposures amongst population groups are arguably the most important consideration from an environmental equity perspective (Brainard *et al*., 2004). A dummy variable taking value 1 for rented and 0 for owned house has been considered in the present study.

Proportion of children and old (Propchild_old): This variable shows the proportion of children (under 15 years of age) and older members (above 55 years of age) in the household. A higher proportion of children and older members makes a household more vulnerable to exposure.

Female Dominated Households (Prop_Female): This variable shows the proportion of female members in the household. A household having a larger number of females is likely to behave differently with respect to defensive activities as well as other activities, hence may be exposed differently. Since no such study exists looking into the gender aspect of household, the present study refrains from making any conjecture about the sign and significance.

Outdoor activity (Outdoor Activity): This variable is measured as the proportion of the outdoor active members to the total members of the household. A household having more active outdoor members is more likely to be exposed to air pollution.

Pollution Monitoring Station (PMS_{1-6}): Since some of the PMSs are in residential and some in industrial areas, a dummy for each PMS has been included to see their respective impact.

Secondary Data

The main source of data for the dependent variable, i.e. SPM, is CPCB. The data is for the period 1999-2003. Time series data of monthly averages of pollution concentrations for SO_2, NO_2 and SPM is collected for all the PMSs in Delhi, which is published by the CPCB as a part of the National Ambient Air Quality Monitoring (NAAQM) Programme. The monthly averages are then used to get the annual averages for the study period of 1999-2003. The average levels of NO_2 and SO_2 have remained within the World Health Organization (WHO) or Minimum National Standards (MINAS) safe limits of 50 $\mu g/m^3$

[15] Ideally, we should have taken a dummy for each religion, but most of the households in our sample belong either to the Hindu or Muslim religion with very few Sikhs and Christians.

and 80 µg/m^3 respectively, both in industrial as well as residential areas during the study period, however the average levels of SPM are much above the safe standards of 200 µg/m^3. Therefore, the annual average SPM levels are of primary concern for this study on air pollution in Delhi.[16]

5. EMPIRICAL ESTIMATION OF EXPOSURE LEVELS AND ENVIRONMENTAL EQUITY

Trend and Mean Exposure Levels

It would be interesting to see how various household groups fare with respect to the highest levels of exposure under each PMS. Table 1 illustrates the distribution of average levels of exposure over the five-year period 1999 to 2003 for different strata of population: slums, middle income and high income across all the PMSs. Column 4 gives the average exposure, whereas columns 1 to 3 give exposure by household types. Figure 2 gives the mean trend of overall exposure and SPM level across all PMSs.

ITO, despite its designation as a residential area by the CPCB, ranks first amongst all the PMSs with an exposure of 591.94 µg/m^3 (row 7). At this PMS, slum households (row 7, column 1) are also the most affected by the exposure. The high traffic volume[17] compounded by the presence of three power plants[18] in the vicinity seems to be the main cause for the high levels of SPM in this area.

The table indicates that barring Ashok Vihar, at all PMS households in slum areas are exposed maximum to air pollution. After ITO, the two primarily industrial PMSs display maximum exposure to pollution.

Table 1: Average Exposure Levels of Different Household Groups

S. No.	Household Group (µg/m^3)			Mean Exposure (µg/m^3) (4)	Pollution Monitoring Station (5)
	Slum (1)	Middle Income (2)	High Income (3)		
1.	459.75	445.76	467.57	457.74	Ashok Vihar
2.	456.71	454.24	387.19	433.62	Janak Puri
3.	585.39	532.24	449.85	524.11	Nizamuddin
4.	604.53	533.89	413.24	517.22	*Shahzada Bagh*
5.	565.70	461.32	397.36	487.11	Siri Fort
6.	637.36	524.70	531.90	564.65	*Shahdara*
7.	731.12	527.05	517.64	591.94	ITO

Source: Own compilation,
Note: The italicized PMS are industrial in nature.

It can be seen that the mean household exposure level follows the same trend as that of the mean SPM in the PMS, though the household exposure level is higher than the SPM level. The figure depicts a fluctuating trend over the study period as in each alternate year the exposure levels increase and then fall again in the subsequent year. Interestingly, various pollution control measures as adopted by the Delhi government during this period like the introduction of unleaded petrol, low-sulphur diesel and Compressed Natural Gas (CNG) have not impinged on the pollution profile, as the SPM levels have not come down over the years. This could be due to the ever-increasing vehicular population in Delhi. The data shows that on an average nearly 100,000 vehicles are registered every year in Delhi, which more

[16] Though there may be many more toxic pollutants present in the ambient air say benzene, but they are not being measured at all the PMSs. Thus, due to the unavailability of time-series data for these pollutants at all the PMSs levels, only SPM is used.

[17] ITO is one of the most busiest intersections in Delhi as given in the CPCB website. The intersection connects the satellite town of Ghaziabad with Delhi.

[18] The three power plants are Indraprastha Power Station, Raj Ghat Power House and Pragati Power Project (or IP Gas Power plant).

than offset the government policies to control air pollution in the city.[19] Besides this, the dust particles carried by wind from Rajasthan desert and Haryana agriculture fields may also be contributing to the SPM levels in the capital especially during summer months.[20]

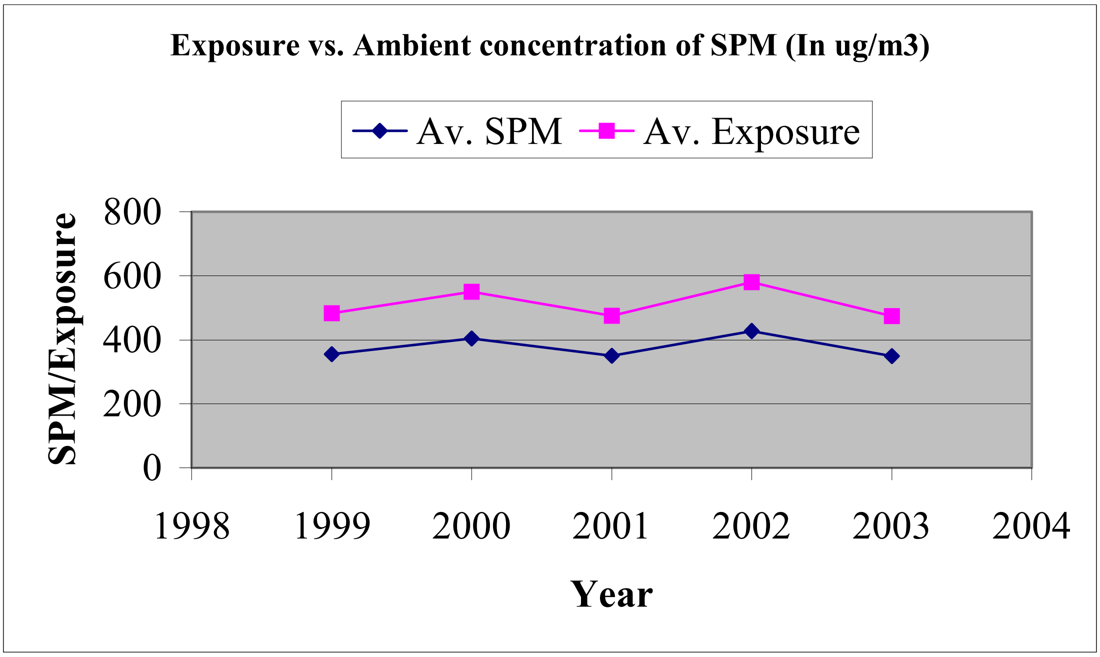

Figure 2: Mean SPM and Household Mean Exposure in all the PMSs

Table 2 gives the mean exposure level for various subgroups based on different socio-economic characteristics such as caste, income, education, and housing characteristics over the period 1999 to 2003.

Table 2: Mean Exposure for Different Categories, 1999-2003 ($\mu g/m^3$)

S. No.	Categories	Mean Exposure
1	**All Persons**	474.93
2	**Lower Castes (SC/ ST)**	500.97
3	**Upper Castes**	469.49
4	**No Secondary School (≥ 18 years)**	491.83
5	**Secondary school (≥ 18 years)**	488.55
6	**Graduate**	466.58
7	**Postgraduate**	448.46
8	**Renter occupied**	481.04
9	**Owner occupied**	473.66
10	**Income (Rs. 0.12 - 1 Lakhs)**	484.41
11	**Income (Rs. 1.12 - 3 Lakhs)**	470.25
12	**Income (Above Rs. 3 Lakhs)**	440.93

[19] See Kathuria (2002, 2004) that has tried to see the impact of CNG and other policy instruments on Delhi's air pollution. The studies do not find a very discerning change in the pollution profile.

[20] See Dave (2001) for an account of the factors contributing to SPM and RSPM levels in Delhi air.

The category wise comparison shows that the lower caste households have statistically significant higher levels of mean exposure as compared with the upper caste households (t = 3.28, p=0.0011). When the mean exposure levels are compared on the basis of average household education, for persons aged 18 and above, the figures show a statistical significant decreasing trend of exposure for increasing number of years of education for the households.[21]

Households staying in rented houses show higher, but statistically insignificant, exposure in relation to owner occupied households (t = 0.75, p=0.44). However, the exposure level of poor households (income category Rs. 0.12-1 lakh per annum) is much higher than that of rich households (income above Rs. 3 lakhs) with the difference statistically significant (t = 3.53, p = 0.0005). This implies that the poorest households are the hardest hit in terms of the mean exposure levels in Delhi, whereas the richest category in the sample bear the least exposure to air pollution.

Based on above analysis, it can be inferred that there exists disproportionate exposure (or environmental inequity) to air pollution. The households represented by the lowest income category, having fewer years of schooling, and belonging to lower castes are prone to be more exposed to the air pollution in Delhi.

Econometric Estimation of Exposure to Air Pollution

In order to see whether environmental equity exists with respect to exposure or that it is disproportionately affects certain castes and religions in different parts of Delhi, the model given in Section 3 is estimated. Table 3 reports the estimates of the log-linear model.[22] Column 2 reports the results for the average SPM for all the PMSs. The White's test shows the presence of heteroskedasticity, thus the model is re-estimated after correcting for heteroskedasticity.

The coefficient of the Caste variable (row 4) shows a positive relationship between caste and the level of exposure. This implies that lower caste households are more exposed to pollution, but the difference is not statistically significant. Similarly, though minority communities are exposed more to pollution, the impact is not statistically significant (row 5). However with respect to household income, the results indicate that a rich household will be less exposed to air pollution. This implies that poor people are more vulnerable to pollution.

With respect to controlling variables, as hypothesized, a household having a higher proportion of vulnerable people (row 7) and more active outdoor members (row 9) tends to have larger exposure from air pollution, whereas, gender distribution (row 8) does not have any significant impact on the exposure.

Row 1 gives the coefficient of Education. Surprisingly, the relation comes out to contrary to the notion that a literate household due to greater awareness would be less exposed. However, the effect of education is not statistically significant. It is generally argued that education often has a threshold effect. The effect of education leading to increased awareness may be only after the household has achieved a certain level of literacy. In order to see this non-linear impact, the model is re-run with a square term of education (Education2).[23] Column 3 of the table reproduces the results.

Based on the sign and significance, it can easily be seen that at the lower level of literacy, the exposure is high but when the literacy level in a household increases, it has a definite negative impact on exposure. This negative relationship could be due to the fact that a household with a higher aggregate education

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[21] The t-statistic for exposure is –1.62 (p = 0.10) between the households with average graduation and post-graduation education and between the households having average secondary schooling and average graduate education, it is –2.02 (p = 0.04).

[22] Given the complexities involved and assumptions made in constructing the exposure index, the analysis was also carried out with the dependent variable as ambient quality of SPM. However, the results were insignificant, hence have not been reported.

[23] For subsequent analysis, Education in square term has been included in the analysis

will be more aware of the negative impacts of air pollution and may have taken preventive measures accordingly.[24] With respect to all other variables, the model behaves identically.

Table 3: Estimates of the Log-Linear Heteroskedasticity Corrected Ordinary Least Squares Model (N = 347) (Dependent Variable = Household specific Exposure Index)

S. No.	Variable (1)	All PMSs (2)	All PMSs (3)
1	**Education**	0.001 (0.77)	0.006* (1.83)
2	**Education^2**		-0.0003* (-1.65)
3	**Income**	-0.014* (-2.91)	-0.0123* (-2.39)
4	**Caste**	0.013 (0.99)	0.014 (1.02)
5	**Religion**	-0.016 (-0.65)	-0.019 (-0.75)
6	**Owned House**	-0.020 (-1.45)	-0.020 (-1.42)
7	**Propchild_Old**	0.287* (11.62)	0.287* (11.75)
8	**PropFem**	0.020 (0.63)	0.022 (0.72)
9	**Outdoor**	0.047* (2.03)	0.046* (1.98)
10	**PMS1_dummy**	-0.400* (-21.60)	-0.401*(-21.82)
11	**PMS2_dummy**	-0.378*(-19.99)	-0.379*(-20.26)
12	**PMS3_dummy**	-0.274*(-12.49)	-0.275*(-12.54)
13	**PMS4_dummy**	-0.308* (-17.07)	-0.308*(-17.32)
14	**PMS5_dummy**	-0.283*(-15.45)	-0.283*(-15.70)
15	**PMS6_dummy**	-0.133*(-7.66)	-0.134*(-7.68)
16	**Constant**	4.72* (140.08)	4.70* (140.75)
17	**R^2**	0.72	0.72
18	**F**	60.03	66.36

Note: Figures in parentheses are t-ratios. * - indicates significance levels at minimum 10% level.

Testing for Robustness

As the construction of the outdoor exposure index is under certain assumptions, for the robustness of the results, the exposure index is re-computed assuming a different exposure for each different category of household members. Table 4 indicates how each type of member has been assumed to be exposed.

Table 4: Different Variants for Constructing Exposure Index – Hours of Exposure Assumed

S. No.	Exposure	Adult Male (In hrs)	Adult Female (In hrs)	Old Male (In hrs)	Old Female (In hrs)	Children (In hrs)
1	**Exposure 1**	5	5	9	6	8
2	**Exposure 2**	5	4	9	6	8
3	**Exposure 3**	5	5	8	5	8
4	**Exposure 4**	5	5	8	6	8
5	**Exposure 5**	5	5	8	7	8

Note: Exposure 1 is same as the one mentioned in Section 3.

Table 5 gives the results for each variant of the Exposure Index. From the table it can easily be inferred that the results are fairly robust to the alternate mode of construction of exposure index. Income (row 3) has a negative relation with the exposure. Similarly, Low Caste households (row 4) are significantly more exposed to pollution in variant 3. Religion (row 5) has no impact on the exposure.

[24] This finding corroborates the earlier results by Jalan *et al.* (2003) and Jalan and Somanathan (2004) where they have found that measures of awareness such as schooling and exposure to mass media have statistical significant effects on adoption of different water pollution preventive measures.

With respect to controlling variables, a household with a larger proportion of active outdoor members (row 9) and more vulnerable people (row 7) tend to have larger exposure. However, the impact of Education becomes insignificant in some variants of the model, though the variable retains the same sign. On the other hand, owning a house (row 6) makes for less vulnerability to pollution exposure but the effect is not statistically significant.

Table 5: Robustness Check: Estimates of the Log-Linear Model for All PMSs (N=347)
Dependent Variable: Log Exposure

S. No.	Variable	Lnexpo1 (1)	Lnexpo2 (2)	Lnexpo3 (3)	Lnexpo4 (4)	Lnexpo5 (5)
1	**Education**	0.006* (1.83)	0.0076* (1.85)	0.0056 (1.59)	0.0057* (1.66)	0.0059* (1.71)
2	**Education^2**	-0.0003 (-1.65)*	-0.0003* (-1.65)	-0.0002 (-1.42)	-0.0002 (-1.46)	-0.0002 (-1.48)
3	**Income**	-0.0123* (-2.39)	-0.0161* (-2.74)	-0.0178* (-3.51)	-0.0157* (-3.15)	-0.0136* (-2.71)
4	**Caste**	0.014 (1.02)	0.0168 (0.98)	0.023* (1.61)	0.0192 (1.38)	0.0156 (1.13)
5	**Religion (Hindu)**	-0.019 (-0.75)	-0.0222 (-0.80)	-0.0194 (-0.77)	-0.0175 (-0.70)	-0.0159 (-0.63)
6	**Owned House**	-0.020 (-1.42)	-0.0217 (-1.28)	-0.0179 (-1.17)	-0.0181 (-1.25)	-0.0185 (-1.31)
7	**Propchild_old**	0.287* (11.75)	0.3514* (12.34)	0.2390* (8.72)	0.2637* (10.83)	0.2864* (12.37)
8	**Propfem**	0.022 (0.72)	-0.0318 (-0.88)	0.0281 (0.80)	0.0306 (0.96)	0.0322 (1.07)
9	**Outdoor**	0.046* (1.98)	0.0637* (2.33)	0.0751* (2.98)	0.0672* (2.89)	0.0591* (2.62)
10	**PMS1_dummy**	-0.401* (-21.82)	-0.4021* (-18.21)	-0.3994* (-20.20)	-0.4026* (-21.55)	-0.4052* (-22.20)
11	**PMS2_dummy**	-0.379* (-20.26)	-0.3869* (-17.52)	-0.3835* (-19.36)	-0.3829* (-20.65)	-0.3819* (-21.10)
12	**PMS3_dummy**	-0.275* (-12.54)	-0.2786* (-11.32)	-0.2785* (-12.15)	-0.2771* (-12.68)	-0.2754* (-12.90)
13	**PMS4_dummy**	-0.308* (-17.32)	-0.3058* (-14.33)	-0.3027* (-15.81)	-0.3048* (-17.06)	-0.3064* (-17.78)
14	**PMS5_dummy**	-0.283* (-15.70)	-0.2818* (-13.31)	-0.2728* (-14.02)	-0.2799* (-15.26)	-0.2862* (-16.04)
15	**PMS6_dummy**	-0.134* (-7.68)	-0.1295* (-6.13)	-0.1312* (-7.20)	-0.1348* (-7.76)	-0.1380 (-8.14)
16	**Constant**	4.70* (140.75)	4.6610* (121.51)	4.7004* (131.36)	4.6966* (143.26)	4.693* (149.32)
17	**R^2**	0.72	0.67	0.70	0.72	0.73
18	**F**	66.36	51.00	63.50	68.51	73.49

Note: Figures in parentheses are t-ratios. * indicates significance levels at minimum 10%.

Based on the results, it can be concluded that the evidence of environmental inequity with respect to caste and religion is fairly weak in Indian context. However, poor people face discrimination in terms of exposure.

Environmental Equity across PMSs types

Since two of the seven PMSs are in industrial areas, the environmental inequity may be less prevalent there, given the fact that it is an industrial area. Thus, a separate analysis is carried out for residential and industrial areas to verify environmental inequity. Table 7 reports the results accordingly. Columns 2 and 3 report results for Residential and Industrial PMSs, respectively. It needs to be mentioned at the outset that since the pollution level is higher at industrial areas, the exposure would be more accordingly. As a result, the defense against exposure through awareness (literacy), defensive expenditure (income), etc. would be relatively less.

From the table, it can be easily seen that the exposure is differently impacted by socio-economic characteristics depending upon where the households are staying. However, Caste (row 4), and religion (row 5) play no role in either locations, but Income certainly plays a key role in reducing exposure to pollution in industrial areas. A higher value of the coefficient in industrial areas (-0.0157) than the residential ones (-0.008) means that the location of such households is an important factor. In fact, our data shows (Table 2) that the poor households are more exposed as a whole.

Table 6: Estimates of the Log-Linear Model with Robust Standard Errors for Residential and Industrial Areas separately (Dependent Variable: Log Exposure)

S. No.	Variable (1)	Residential Areas (2)	Industrial Areas (3)
1	**Education**	0.0108* (2.66)	-0.0035 (-0.55)
2	**Education^2**	-0.0005* (-2.26)	0.0001 (0.59)
3	**Income**	-0.0083 (-1.24)	-0.0157* (-1.86)
4	**Caste**	0.0263 (1.43)	-0.0154 (-0.69)
5	**Hindu**	-0.0157 (-0.47)	-0.3375 (-1.39)
6	**Owned House**	-0.0219 (-1.37)	0.0053 (0.16)
7	**Propchildold**	0.2926* (9.99)	0.2880* (6.92)
8	**Propfem**	0.0350 (0.81)	0.0030 (0.08)
9	**Outdoor**	0.0603* (2.10)	0.0047 (0.12)
10	**PMS1_dummy**	-0.4005* (-20.20)	
11	**PMS2_dummy**	-0.3808* (-19.73)	
12	**PMS3_dummy**	-0.2746* (-12.58)	
13	**PMS4_dummy**		-0.1757* (-9.70)
14	**PMS5_dummy**	-0.2791* (-14.41)	
15	**Constant**	4.6677* (119.03)	4.673* (83.80)
16	**R^2**	0.74	0.66
17	**F**	63.04	23.11
18	**N**	245	102

Note: Figures in parentheses are t-ratios. * indicates significance levels at minimum 10%.

Education has a direct impact on exposure in a residential area (rows 1 and 2), however in Industrial areas, where the level of pollution is relatively high, education plays no role in defensive activities. The coefficient of the house-ownership variable (row 6) behaves differently in the areas, though it is not significant at either location. Row 7 examining the vulnerability of older people and children indicates that irrespective of location, residential or industrial, this group is exposed more from pollution. The impact on outdoor active members has come out to be correct in residential areas. However, when a dwelling has a house in industrial locations, it does not matter whether the household members are outdoor active or not. Thus the results differ across the two kinds of PMSs.

Environmental Equity across PMSs types – Robustness check

In order to test for the robustness of the results, the exposure index is computed differently using hours of exposure calculated as given in Table 4. The results for the two groups of PMSs are given in Tables 7 and 8 respectively.

From the table, it can be seen that results are fairly robust for alternate constructions of exposure index. For industrial PMS (see Table 8), there is no change in results for any of the socio-economic and demographic variables. However for Residential PMS (see Table 7), Income and Caste becomes significant in two variants of the model.

Table 7: Robustness Check: Estimates of the Log-Linear Model for Residential Areas
Dependent Variable: Log Exposure (N = 245)

S. No.	Variable	Lnexpo1 (1)	Lnexpo2 (2)	Lnexpo3 (3)	Lnexpo4 (4)	Lnexpo5 (5)
1	**Education**	0.0108* (2.66)	0.0127* (2.71)	0.0099* (2.39)	0.0100* (2.50)	0.0103* (2.55)
2	**Education^2**	-0.0005* (-2.26)	-0.0006* (-2.28)	-0.0005* (-2.07)	-0.0005* (-2.13)	-0.0005* (-2.14)
3	**Income**	-0.0083 (-1.24)	-0.0115 (-1.51)	-0.0139* (-2.08)	-0.0119* (-1.81)	-0.0100 (-1.49)
4	**Caste**	0.0263 (1.43)	0.0289 (1.31)	0.0357* (1.90)	0.0310* (1.69)	0.0267 (1.46)
5	**Hindu**	-0.0157 (-0.47)	-0.0190 (-0.53)	-0.0217 (-0.65)	-0.0169 (-0.51)	-0.0125 (-0.38)
6	**Owned House**	-0.0219 (-1.37)	-0.0262 (-1.39)	-0.0200 (-1.15)	-0.0198 (-1.20)	-0.0197 (-1.24)
7	**Propchild_old**	0.2926* (9.99)	0.3601* (10.83)	0.2374* (7.14)	0.2662* (9.19)	0.2924* (10.68)
8	**Propfem**	0.0350 (0.81)	-0.0222 (-0.47)	0.0412 (0.86)	0.0454 (1.06)	0.0481 (1.19)
9	**Outdoor**	0.0603** (2.10)	0.0821* (2.54)	0.0893* (2.84)	0.0812* (2.87)	0.0728* (2.67)
10	**PMS1_dummy**	-0.4005* (-20.20)	-0.4027* (-17.14)	-0.3971* (-18.46)	-0.4010* (-19.85)	-0.4043* (-20.58)
11	**PMS2_dummy**	-0.3808* (-19.73)	-0.3906* (-17.33)	-0.3838* (-18.33)	-0.3839* (-19.84)	-0.3835* (-20.57)
12	**PMS3_dummy**	-0.2746* (-12.58)	-0.2799* (-11.35)	-0.2780* (-11.98)	-0.2765* (-12.61)	-0.2748* (-12.91)
13	**PMS5_dummy**	-0.2791* (-14.41)	-0.2791* (-12.33)	-0.2675* (-12.80)	-0.27549* (-13.96)	-0.2825* (-14.71)
14	**Constant**	4.6677* (119.03)	4.616* (106.30)	4.6675* (105.25)	4.6589* (120.84)	4.6520* (129.58)
15	**R^2**	0.74	0.70	0.72	0.74	0.75
16	**F**	63.04	50.47	60.13	64.94	71.21

Note: Figures in parentheses are t-ratios. * indicates significance levels at minimum 10%.

The results thus point to weak evidence of environmental inequity in Delhi. Though the lower caste households' exposure is slightly high, the inequity does not exist pertaining to the religion. However, as found in a number of studies elsewhere, the results support that poor people face higher exposure to air pollution than the rich or middle class people especially when located in industrial areas. With respect to controlling variables, education plays a vital role in reducing exposure once it crosses a threshold and provided the households are staying in a residential area. On the whole, vulnerable members in the households suffer more exposure irrespective of the region's characteristics.

Table 8: Robustness Check: Estimates of the Log-Lin Model for Industrial Areas
Dependent Variable: Log Exposure (N=102)

S. No.	Variable	Lnexpo1 (1)	Lnexpo2 (2)	Lnexpo3 (3)	Lnexpo4 (4)	Lnexpo5 (5)
1	**Education**	-0.0035 (-0.55)	-0.0040 (-0.50)	-0.0044 (-0.70)	-0.00410 (-0.67)	-0.0039 (-0.63)
2	**Education^2**	0.0001 (0.59)	0.0002 (0.57)	0.0002 (0.79)	0.0002 (0.76)	0.0002 (0.73)
3	**Income**	-0.0157* (-1.86)	-0.0210* (-1.99)	-0.0217* (-2.50)	-0.0192* (-2.29)	-0.0167* (-2.04)
4	**Caste**	-0.0154 (-0.69)	-0.0156 (-0.53)	-0.0075 (0.34)	-0.0093 (-0.43)	-0.0111 (-0.51)
5	**Hindu**	-0.3375 (-1.39)	-0.0386 (-1.34)	-0.0178 (-0.75)	-0.0240 (-1.03)	-0.0301 (-1.30)
6	**House owned**	0.0053 (0.16)	0.0149 (0.37)	0.0094 (0.28)	0.0069 (0.21)	0.0045 (0.14)
7	**Propchild_old**	0.2880* (6.92)	0.3467* (6.60)	0.2601* (5.79)	0.2725* (6.50)	0.2843* (7.14)
8	**Propfem**	0.0030 (0.08)	-0.0448 (-0.88)	0.0049 (0.12)	0.0050 (0.13)	0.0498 (0.13)
9	**Outdoor**	0.0047 (0.12)	0.0111 (0.22)	0.0304 (0.70)	0.0245 (0.59)	0.0186 (0.47)
10	**PMS4_dummy**	-0.1757* (-9.70)	-0.1781* (-7.99)	-0.1748* (-9.30)	-0.1720* (-9.45)	-0.1692* (-9.52)
11	**Constant**	4.673* (83.80)	4.6441* (68.85)	4.6491* (80.76)	4.6518* (85.42)	4.6547* (89.19)
12	**R^2**	0.66	0.59	0.62	0.64	0.66
13	**F**	23.11	17.10	21.74	22.25	22.73

Note: Same as Table 7.

6. CONCLUDING REMARKS

This paper has attempted to find out the evidence of environmental inequity i.e., whether there is any divergence in the households' exposure to air pollution on account of differences in their socio-economic characteristics in Delhi, India. Primary data on various socio-economic traits of a sample of 347 households was obtained with the help of a structured questionnaire while the data on air pollution (SPM) was collected from the CPCB for the period 1999 to 2003. For the purpose of the study, an SPM exposure index has been computed by combining the primary as well as the secondary data. This exposure index is then used to see the effect of various socio-economic and demographic characteristics of different communities around seven pollution monitoring stations in Delhi using a multivariate regression equation.

The econometric analysis shows that other things being equal, the economically backward communities are the most affected by the exposure to air pollution on an average. The effect is quite pronounced when they are staying in industrial areas. However, the study could not find any evidence of environmental inequity due to religion and the evidence was weak for the communities, which are socially backward.

Education, composition of household members and ownership of house are other important factors influencing exposure. Moreover, the separate analysis of residential and industrial areas suggest that human exposure to air pollution is indeed dependent, though not systematically, on the location of residence besides their socio-economic status. The main reason which can be put forward for this relationship is that the poor in Delhi, mainly represented by the slum dwellers do not have better means to protect themselves against the effects of air pollution, directly or indirectly. Mushrooming of slums near the industrial areas is a well-known fact in Delhi. Besides facing vehicular pollution on account of their outdoor activities for earning, they are exposed to industrial pollution due to living in close proximity to highly industrialized or commercial locations, such as Shahdara and ITO.

Since two-thirds of the air pollution in Delhi is due to the vehicular pollution, the Delhi government has taken up some steps such as the use of alternative fuel types like CNG, an increase in fee for registration of new vehicles and parking, and has partially implemented plans of closure/shifting of polluting units to curb the menace of air pollution. Still, the problem is far from fully addressed. What is indeed required is to decongest the roads by using some road pricing policies like peak-load pricing and encouraging people to use collective transport means like Metro Rail and the proposed introduction of the high-capacity bus system (HCBS).

From a policy standpoint, social factors that have led to disparities in air pollution exposure as found in the study also need to be given due consideration. Recent research elsewhere has suggested that the process may due linked to lower housing costs in less environmentally desirable areas (Oakes *et al.*, 1996). Another policy aspect is the creation of a greater awareness and provision of more information on health hazards from air pollution so as to induce people to engage in defensive activities.[25]

One of the limitations of the present study is that the sampling sites are chosen from the surrounding areas of PMSs because the data on air pollution is available for the designated PMSs only and not for every part of the city. Moreover, exposure depends on wind direction and velocity; these two metrological factors need to be used while ascertaining the exposure. Lastly, the study uses only SPM, however, there are other air toxics, which need to be used to compute exposure.

[25] In fact, the Action Plans prepared by the Ministry of Environment & Forests (1997) in the mid 1990s and the recent plan by the Department of Environment (2005) also emphasize the creation of greater awareness and public and civil society participation in reducing the menace of overall pollution in the city.

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