Key airborne pollutants – Impact on human health in Manali, Chennai

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Exposure to air pollution is an inescapable part of our urban life. In this study, the interaction patterns of air pollutants, SO_2, NO_x, SPM and PM_{10} are investigated based on measured database of the study area in Manali, near Chennai. This study is necessary, since these pollutants violate the prescribed norms of the NAAQ Standards. The air quality of SPM and PM_{10} based on exceedence factor for industrial average was assessed. It was found to fall under the moderate pollution category and this position is maintained. The health risks due to air pollutants are quantified by estimating the relationship between air quality and health effects. Health-related information was gathered through survey and the result is presented in spatial form. This study found that the inhabitants of Manali and surrounding villages were affected by respiratory problems, asthma and premature death. Thus the environmental concerns prevailing in Manali are a serious issue.

Keywords: Airborne pollutants, air quality assessment, health impact, industrial air pollution.

AIR pollution has adverse impact on human health as well as the health of other living entities and stress vegetation. Depending upon the lifetime of the pollutants, location of the source and prevailing air currents, receptors may be located at homestead, local, regional or global levels, at time intervals from near instantaneous, to several decades[1]. Air pollution and its impact on people's health and the environment is a matter of great concern. Heavy reliance on coal in power production and a rapidly growing car fleet, usually in combination with outdated technologies and poor maintenance have led to a concentration of air pollutants, far exceeding the limits of both national air quality standards and air quality guidelines recommended by the World Health Organization[2].

Good air quality is essential for the health of people and the environment; although significant improvements have been made in many countries over the last 2–3 decades, air quality, particularly in urban areas, remains a priority issue on most national environmental agendas[3]. Particulate and gaseous emission of pollutants from industries and auto-exhausts is responsible for rising discomfort, increasing airway diseases, decreasing productivity and deterioration of artistic and cultural patrimony in urban centres[4]. The presence of air pollutants over the prescribed limit in the lower atmosphere is not only injurious to humans, but also to animals, foliage, fruits, vegetables and microbial life and may even damage property[5]. Urban air pollution is a major focus of public health concern and regulatory activity[6].

The purpose of this study is to quantify (a) urban air quality, (b) health effects (morbidity and mortality), and (c) cross-sectional survey. The study consists of four steps: (i) To determine the concentration of air pollution levels. (ii) To estimate the health effects. (iii) To examine the association of tiny air pollutants with that of various causes due to which premature death cases occurred, in different age groups of both genders. (iv) To quantify the cases of premature death and morbidity associated with air pollution through the survey questionnaire collected in Manali.

Materials and methods

Area description

Chennai is one of the metropolitan cities of India. The study area, Manali (13°09′N, 80°15′E) is an industrial complex and is the most air pollution-sensitive area, situated about 20 km north of Chennai, connected by road. It comprises an area of 16 km^2, intersected by villages and is inside the inhabited area. Manali has an average rainfall of 6 cm. The total population of 28,597 consists of 15,080 males and 13,517 females (census, 2001). There was an increase of 20% decadal variation of population from 1951 to 2001. The area consists of various industries like oil refineries, fertilizer plants, chemicals, fabric yarn and steel, etc. which have existed for more than two decades. There are 28 categories of industries (major–20, minor–3 and small–5) located in Manali, which include CPCL, MFL, TNPP, Manali Petro Chemical, etc. Field survey at 16 GPS locations was conducted (Figure 1).

Urban air quality

Rapid industrialization, urbanization and development of transport network have added impetus to economic development at the cost of environment. Although such development is integral to economic growth, the problem lies in their unfettered proliferation in India, leading to severe

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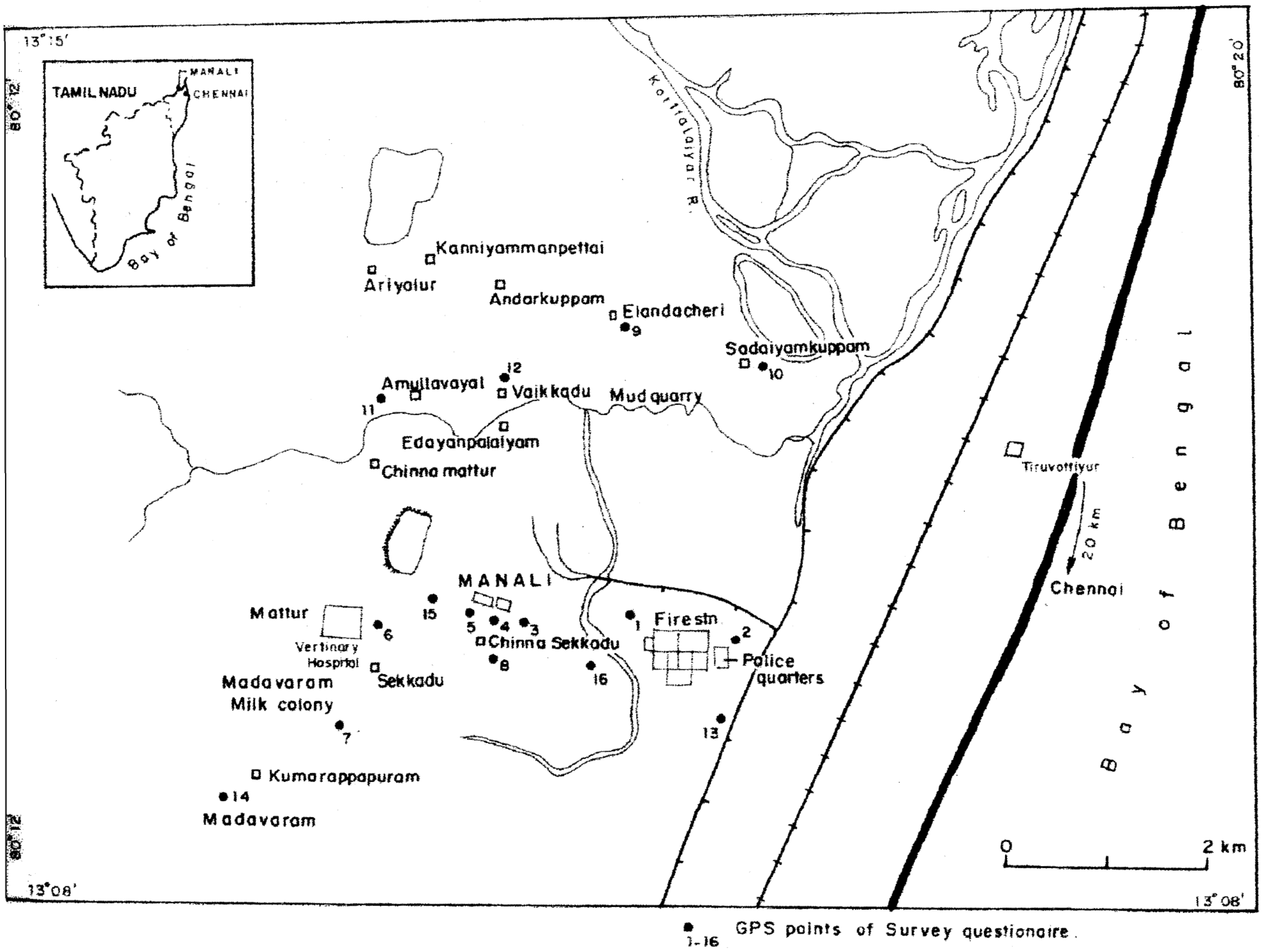

Figure 1. Location map of study area showing sixteen GPS locations.

environmental degradation[7], particularly since 1970. Unplanned urbanization and industrialization are causing deterioration of the environment and quality of life in developing countries. It is essential to assess the spatial distribution of air quality and its impact on human beings in the urban region[8].

Traditional approaches to environment management consist in identifying a pollutant source and then trying to trace emissions through the environment to observe, who or what might be affected. However, the exposure science approach to environmental management starts with the receptor of those pollutants – humans. It identifies and measures pollutants that have reached humans, and then traces the pollutants back to their sources. The traditional approach has been considered for this study.

Key airborne pollutants

Airborne pollutants consist of natural contaminants, aerosols, gases and vapours. They can be broadly classified into two categories, primary and secondary. Primary air pollutants are emitted from direct sources. They consist of gaseous pollutants, sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particles, suspended particulate matter (SPM) less than 100 μm in aerometric diameter, respirable suspended particulate matter ($RSPM/PM_{10}$) less than 10 μm in aerometric diameter. This study covers classical pollutants, viz. SO_2, NO_x, SPM and PM_{10} and these are investigated based on the measured database of Tamil Nadu Pollution Control Board (TNPCB). Monitoring of pollutants is carried out for 24 h (4-h sampling for gaseous pollutants and 8-h sampling for particulate matter), twice a week (Monday and Thursday), to have 104 observations in a year.

Methods of monitoring air quality standards

An air quality monitoring station had been established in Manali by the TNPCB. Respirable dust high volume sampler is an instrument used for monitoring of air quality parameters and provides 8 h continuous readings. This instrument APM 460Dx of Envirotech based on technology from NEERI, Nagpur separates SPM and PM_{10} and helps in estimation of their concentrations. The instrument has provision for incorporation of gaseous sampling unit, for simultaneously monitoring gaseous pollutants like SO_2 and NO_x present in the ambient air. The gaseous sampling module has impingers for absorption of gaseous pollutants into suitable absorbing solutions. Pollutant concentrations are subsequently estimated by standard methods of analysis in the laboratory.

SO_2 is measured by improved West and Gaeke method. SO_2 in ambient air is absorbed in a solution of 0.04 ml sodium tetrachloromercurate and analysed using colorimetric technique in the laboratory. NO_x is measured by modified Jacob and Hochheiser method. NO_x in ambient air is absorbed in a solution of sodium hydroxide and sodium arsenite and analysed using colorimetric technique. SPM is measured by gravimetric technique (HVS-Filtration. PM_{10} is measured by gravimetric technique under HVS-Filtration method on a pre-weighed glass micro fibre filter paper (GFA/EPM 2000 – Whatman). Difference in the weight of filter paper gives the amount of dust collected and thus the concentration is determined. The Central Pollution Control Board (CPCB), Delhi has prescribed a maximum permissible level for each air pollutant for specific areas. These are known as NAAQ (National Ambient Air Quality) Standards, which are the levels of air quality with an adequate margin of safety. These standards are necessary to protect public health, vegetation and property. The NAAQ Standards prescribed are shown in Table 1.

Air quality assessment

The air quality of different cities/towns with respect to air pollutants has been compared with the respective NAAQ standards and has been categorized into four broad categories based on an exceedence factor (EF), which is calculated as follows:

$$\text{Exceedence factor} = \frac{\text{Observed annual mean concentration of criteria pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

Table 1. National Ambient Air Quality Standards

Pollutant (μg/m³)	Time weighed average	Concentration in ambient air: Industrial area	Residential, rural and other areas	Sensitive area
SO_2	Annual	80	60	15
	24-h	120	80	30
NO_x	Annual	80	60	15
	24-h	120	80	30
SPM	Annual	360	140	70
	24-h	500	200	100
PM_{10}	Annual	120	60	50
	24-h	150	100	75

The four air-quality categories are: Critical pollution (C): when EF is more than 1.5; High pollution (H): when EF is between 1.0 and 1.5; Moderate pollution (M): when EF is between 0.5 and 1.0; and Low pollution (L): when the EF is less than 0.5.

It is obvious from the above categorization that the locations in either of the first two categories actually violate the standards, although with varying magnitude. Those falling in the third category meet the standards as of now, but are likely to violate them in future, if pollution continues to increase and if it is not controlled. However, locations in low pollution category have pristine air quality and such areas are to be maintained at low pollution level by way of adopting preventive and control measures[9].

Health effects

Air pollution and its impact on human health have been considered as a serious problem in urban areas. Since the beginning of the last century, many events of air pollution have been associated with increase in mortality, for example, Meuse Valley[10] in 1930. The prime factors affecting human health due to air pollution depend upon: (a) nature of pollutants, (b) concentration of pollutants, (c) duration of exposure, (d) state of health of the receptor and (e) age group of the receptor. Susceptibility to ill-health effects due to air pollution is high among infants, the elderly and the infirm[11]. Details of health effects due to major air pollutants are shown in Table 2.

Efforts towards reduction of air pollution require quantitative knowledge about the relationship between exposure to air pollution and human health. The study addresses this concept and health effects of SO_2, NO_x, SPM and PM_{10} pollutants in Manali. Health risk due to air pollution is more in children than in adults. This is because: (a) children spend more time outside; (b) their general stamina is still building up; (c) they often take in more air while breathing; (d) their lungs are at a developing stage, and (e) they are not aware of air pollution and its seriousness. Air pollution can cause asthma, and can worsen symptoms in children and adults who already have asthma or other lung conditions. It can affect long-term lung development in children.

Based on epidemiological studies in several countries, there is conclusive evidence of a link between particulate air pollution and adverse health effects. Ambient particulate matter is composed of a heterogeneous mixture of particles varying in size and chemical composition. Particles differ in source, size range, formation mechanism, and chemical composition, and are characterized by various physical and chemical properties. While physical properties affect the transport and deposition of particles in the human respiratory system, chemical composition determines their impact on health[12]. Suspended particulate matter is ubiquitously recognized as the most important air pollutant in

Table 2. Air pollutants, sources, and their effects on human health

Pollutants – sources	Health effects
NO_x – Fuel combustion at high temperature	Irritation of pulmonary tract affecting functioning of lungs[20]. Increased risk of viral infections, higher respiratory illness rates, eye burning, airway resistance, chest tightness and discomfort[21].
SO_2 – Fossil fuel combustion; metal smelting and petrochemical industries; home heating/cooking with coal	Irritation of eyes, respiratory system[22], increased mucus production, cough and shortness of breathe[20]. Aggravates heart and lung diseases, increases chronic bronchitis, asthma and cancer[23].
SPM – Biomass and fossil fuel combustion; in home heating, industry; motor vehicle engines; cigarette smoke	Respiratory diseases/bronchitis, reduces visibility[24].
PM_{10} – Building and road construction, diesel trucks and buses; forest fires; open air refuse burning; industries; re-suspension of road dust	Associated with mortality[23]. Respiratory illness, including chronic bronchitis, increases asthma attacks, pulmonary emphysema[21].

terms of human health effects, considering that many epidemiological studies substantiate significant associations between concentration of PM in air and adverse health impacts[13,14].

Additional support for air pollution-related mortality occurring outside of the hospital, with the likelihood of significant shortening of life span is provided by recent studies reporting associations between particulate matter and heart rate, heart rate variability, and arrhythmia[15–18]. The findings suggest significant current and long-term effects of particulates on new cases of heart attacks and angina, reinforcing the disease pathways identified in epidemiological studies. Long-term air pollution exposure is also a determinant of recently diagnosed chronic lung conditions and reports of shortness of breath[19].

Airborne pollutants, SPM and PM_{10} are as a worldwide concern, since they are associated with serious human health effects, such as chronic respiratory problems, asthma and mortality. If the concentration SPM and PM_{10} exceeds the prescribed levels of NAAQ standards specified for the respective category of areas and is maintained at the same level continuously, it may lead to serious health effects, including mortality.

Cross-sectional survey

A survey questionnaire relating to air pollution, health effects, local economic information and other factors regarding suggestions for improvement of the environmental concerns, was circulated for public perception and to gain a better understanding of public opinion. The survey was based on a mix of written responses to the questionnaire as well as personal interviews. The survey was conducted in 16 locations during June – December 2004. Hundred respondents, both adults and children living in Manali and the surrounding villages, mainly from urban poor category, were asked about the recent trends in air quality in their areas, contributing sources, and activities that had improved or worsened air quality in recent years. They were also asked about the adverse health effects, such as asthma, eye problems, chronic respiratory, and skin-related problems and premature mortality. The purpose of the survey was to compare the perceptions of respondents with that of the findings of the current trends of air quality and its health effects.

Results and discussion

Air pollutants concentration – findings

Interactive graphs were drawn for monthly average concentration of SO_2, NO_x, SPM and PM_{10} from 1997 to 2004 (Figures 2 and 3). The x-axis represents months from January to December in each year. The y-axis represents monthly average values of concentration of pollutants.

Sulphur dioxide

Seasonal variations of maximum average concentration values of SO_2 from 1997 to 2004, based on the highest monthly value in each season are indicated in respective yearly order in Figure 2: (i) summer (March–June) – 23.2, 18.3, 21.1, 24.4, 23.3, 43.9, 33.9, 27.8 $\mu g/m^3$; (ii) pre-monsoon (July–Oct.) – 29, 22.3, 29.7, 27, 17.6, 37.3, 26, 27.1 $\mu g/m^3$; and (iii) winter (Nov.–Feb.) – 35.2, 32.9, 22.9, 22.2, 27.1, 45.1, 33.1, 19.6 $\mu g/m^3$. It is observed that the average concentration was high in winter, followed by monsoon and summer. However, it is within the permissible annual standards.

Nitrogen oxide

Seasonal variations of maximum average concentration values of NO_x from 1997 to 2004, based on the highest monthly value in each season are indicated in respective yearly order in Figure 3: (i) summer – 17.1, 23.7, 13.1, 23.5, 30, 28.2, 51.9, 53.3 $\mu g/m^3$; (ii) pre-monsoon – 28.7, 28.9, 22.7, 17.6, 34.9, 22.3, 51.6, 33 $\mu g/m^3$; and (iii) winter – 18.5, 44.3, 12.5, 20.1, 27.1, 50.9, 15.6, 43.5 $\mu g/m^3$. During 1998, 2002 and 2004, the concentration values were high in winter, followed by monsoon and summer. The air quality status based on the EF indicates that during

1997 to 2002 it was in the low pollution category; in 2003 it increased to the moderate category and again in 2004, it was at the low pollution category.

Suspended particulate matter

The seasonal variations of minimum, maximum and average concentration values of SPM from 1997 to 2004 are

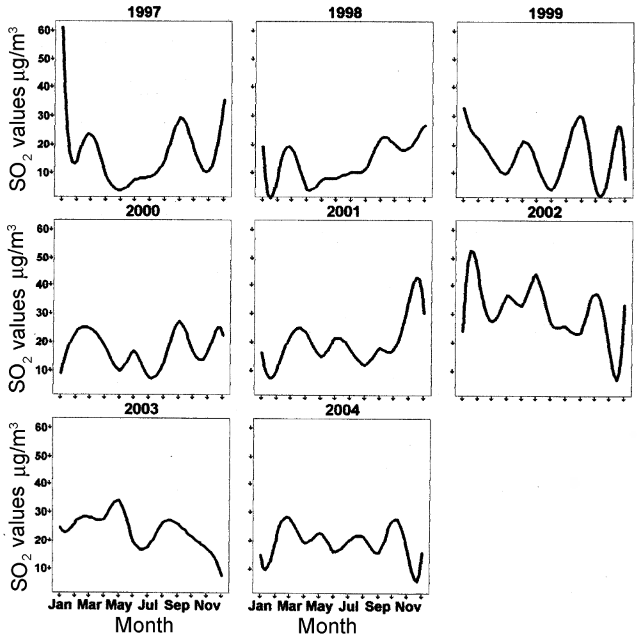

Figure 2. Monthly average concentration of SO_2 from 1997 to 2004.

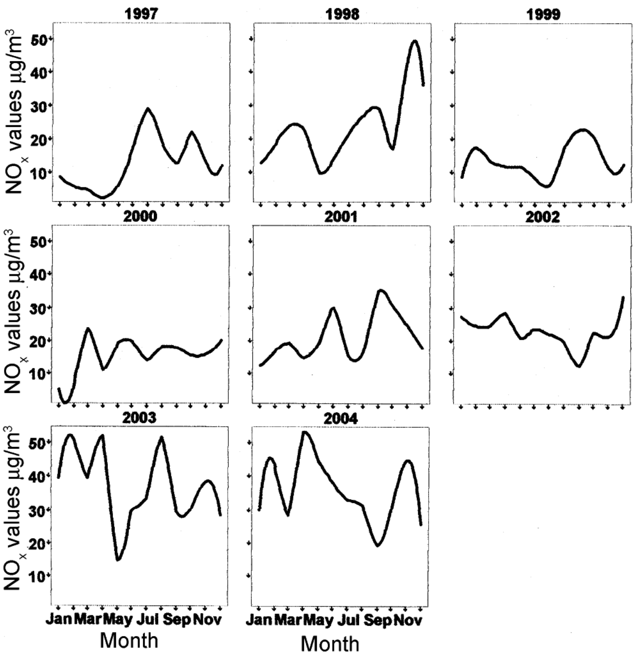

Figure 3. Monthly average concentration of NO_x from 1997 to 2004.

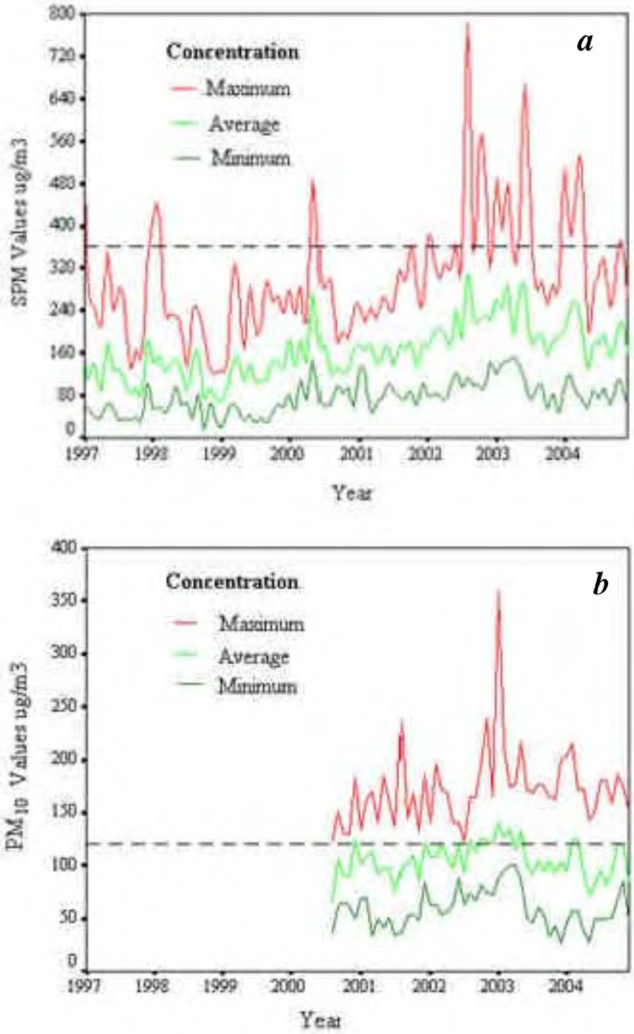

Figure 4. Annual concentration of SPM (***a***) from 1997 to 2004 and PM_{10} (***b***) from August 1997 to 2004.

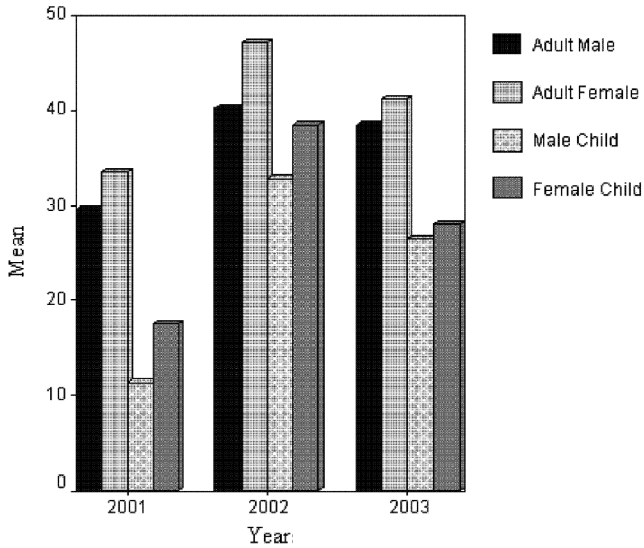

Figure 5. Bronchial asthma cases from 2001 to 2003.

Table 3. Hospital admissions for treatment of asthma cases – season-wise maximum

Year	Season	Adult male	Adult female	Male child	Female child	Month with high rate of admission
2001	Summer	35	26	7	17	Jun.
	Monsoon	46	48	22	39	Aug.
	Winter	52	59	32	46	Feb.
2002	Summer	55	62	40	50	May
	Monsoon	42	60	38	45	Aug.
	Winter	40	45	40	45	Nov.
2003	Summer	40	45	38	36	Mar
	Monsoon	30	35	25	28	Aug.
	Winter	44	45	20	26	Nov.

shown in Figure 4 *a*. The highest monthly value in each season is indicated in respective yearly order: (i) summer – 178, 146, 151, 270, 176, 241, 287, 256 μg/m^3; (ii) pre-monsoon – 131, 160, 145, 173, 178, 311, 193, 194 μg/m^3; and (iii) winter – 185, 94, 184, 174, 198, 259, 241, 220 μg/m^3. During 2002 and 2003, the concentration values were high in winter, followed by monsoon. Based on the NAAQ Standards, air quality in Manali was categorized pollutant and year-wise. It is observed that SPM air quality status from 1997 to 2000 was in the low pollution category and during 2001 to 2004, it was in the moderate pollution category. The low pollution category has pristine air quality and such areas are to be maintained at low pollution levels by adopting preventive and control measures.

Respirable particulate matter

Monitoring of PM_{10} commenced in Manali from August 2000. Seasonal variations of minimum, maximum and average concentration values of PM_{10} from 2000 to 2004 are shown in Figure 4 *b*. The concentrations of this pollutant are classified in three categories. (1) On seasonal variation basis: The highest monthly value in each season is indicated below in respective yearly order: (i) premonsoon – 106, 110, 126, 105, 120 μg/m^3; (ii) winter – 124, 122, 141, 125, 121 μg/m^3; (iii) and summer – 114, 120, 134, 125 μg/m^3. (2) On annual average basis: The annual average value from August to December 2000 was 95.2 μg/m^3; from January 2001 to December 2002 it was 100.16 μg/m^3; from January to December 2002 it was 113.5 μg/m^3; from January to December 2003 it was 111.66 μg/m^3; and from January to December 2004 it was 99.25 μg/m^3. (3) On categorization basis: The air quality status based on EF indicates that during 2000 to 2004 it was in the moderate pollution category. This category is likely to violate the standards in future, if high pollution level is continuously maintained and is not controlled.

Morbidity data – findings

Morbidity data were collected from the Primary Health Centre, Manali, which consists of bronchial asthma, respiratory disorders, eye conjunctivitis, foreign particles in the eye, skin scabies and other skin infections.

Asthma cases

Season-wise distribution of hospital admissions for treatment of asthma is shown in Figure 5 from April 2001 to December 2003. Hospital admissions for treatment of Asthma at season-wise maximum in the study area are shown in Table 3. Generally, both adult male (am) and adult female (af) were affected by asthma. Females are more affected and considerably in higher numbers for treatment of asthma. Though both male and female children (mc and fc) were affected, hospital admissions with respect to female children is higher. A comparison of the hospital admissions for treatment of asthma, with that of the air pollutant levels that prevailed during that particular period, indicates that prevalence of high rate of air pollution caused increased number of hospital admissions for treatment of asthma.

In May 2002, the maximum value of PM_{10} pollutant was 120 μg/m^3 and that of SO_2 was 43.9 μg/m^3 according to the air quality data. Comparison of air quality data with morbidity data reveals that hospital admissions for treatment of asthma were as high as am 55; af 62; mc 40; fc 50. It was further observed that the total number of cases recorded for treatment of various diseases for new cases was 2998, old cases 1554, as against the total population of the Manali area itself, which was 28,597.

Respiratory problem cases

Season-wise distribution of hospital admissions for treatment of respiratory problems is given in a bar chart from April 2001 to March 2004 (Figure 6). Hospital admissions for treatment of respiratory problems on season-wise maximum are shown in Table 4. Generally, both adult male and female were affected by respiratory problems. Females are more affected and were considerably in higher numbers for treatment. As for the children, both male and female children were affected.

In winter 2002, the maximum value of PM_{10} pollutant was 141 μg/m^3, NO_x 50.9 μg/m^3, SO_2 33.1 μg/m^3 and

Table 4. Hospital admissions for treatment of respiratory cases – season-wise maximum

Year	Season	Adult male	Adult female	Male child	Female child	Month with high rate of admission
2001	Summer	53	74	–	–	Apr. (data not available)
	Monsoon	302	710	412	418	Sep. and Oct.
	Winter	45	262	37	93	Nov. to Feb. 2002
2002	Summer	132	279	156	184	Apr. and May
	Monsoon	170	422	156	140	During all months
	Winter	318	469	187	255	Very high during all months
2003	Summer	380	455	354	241	During all months
	Monsoon	414	441	425	474	Jul. to Sep.
	Winter	39	136	488	360	Nov.

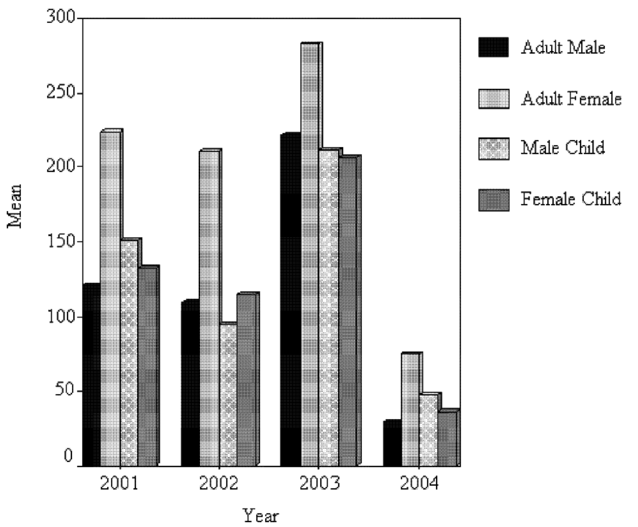

Figure 6. Respiratory problems recorded from April 2001 to March 2004.

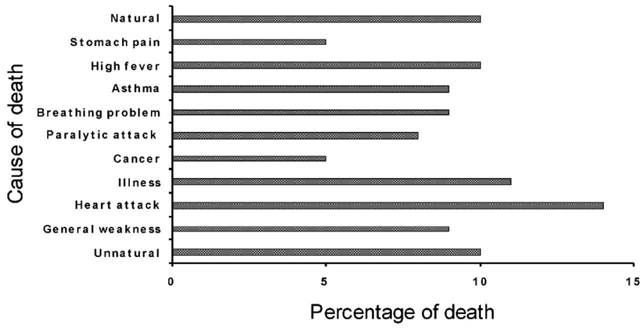

Figure 7. Distribution of various factors contributing to death cases.

SPM 259 μg/m^3 according to the air quality data. Comparison of the data with morbidity data reveals that hospital admissions for treatment of respiratory diseases were high in am 318, af 469, mc 187 and fc 255. It was further observed that the total number of cases recorded for treatment of various diseases for new cases was 3280, old cases 1868, as against the total population of the area.

Eye and skin problem cases

In November 2002, both adults and children were affected with eye problems. In Feb. 2002, female and male children were more affected with skin problems.

Mortality data – findings

Data regarding death were collected from the Town Panchayat, Manali, based on birth and death records from 1998 to June 2005. Table 5 shows the year and gender-wise death cases that occurred in Manali households under various age groups. It can be noticed that the total number of deaths recorded has been consistently on an increase each year. It is also observed generally that the number of death cases that occurred among males is higher than females. A comparison of the number of death cases with that of the age groups indicated that the number of death cases in 40–59 age group of both male and female category are high, followed by the age group 70.

It is seen that ten male and six female death cases occurred particularly in May 2002. This is the highest recorded number of death cases, compared to other periods according to available data. It is further observed that the percentage of deaths due to heart attacks is considerably high, compared with other causes for death (Figure 7). The tiny air pollutant PM_{10} is of prime concern, as it triggers increase in cases with breathing problems, asthma and heart attacks.

Cross-sectional survey

Among the villages that intersect Manali, the inhabitants of Amullavayal, Vaikkadu, Elandacherri and Sadaiyankuppam villages were severely affected by asthma (Figure 8). Respiratory problems were noticed at the rate of 8 to 10 persons in each village. Similarly, 4 to 8 persons were affected by the same problem in Chinna sekkadu, near bus stand and police quarters areas. In the remaining areas, an average of 2 to 3 persons were affected. While conducting the second round of survey in December 2004, the res-

Table 5. Death cases that occurred in Manali households from 1998 to June 2005

		Death cases in numbers						
		Age group						
Year	Gender	0–9	10–19	20–39	40–59	60–69	>70	Total
1998	Male	1	0	13	18	12	16	60
	Female	0	0	4	7	5	15	31
1999	Male	1	0	8	20	14	19	62
	Female	2	3	3	3	4	12	27
2000	Male	1	1	4	20	12	14	52
	Female	0	1	4	8	4	18	35
2001	Mal	0	0	7	18	9	21	55
	Female	1	0	3	15	6	24	49
2002	Male	0	0	12	25	18	21	76
	Female	1	1	3	12	3	16	36
2003	Male	1	0	10	30	11	28	80
	Female	0	2	6	7	9	8	32
2004	Male	1	0	11	22	10	21	65
	Female	0	2	6	7	8	19	42
2005	Male	0	1	2	7	3	10	23
	Female	0	1	3	3	1	4	12

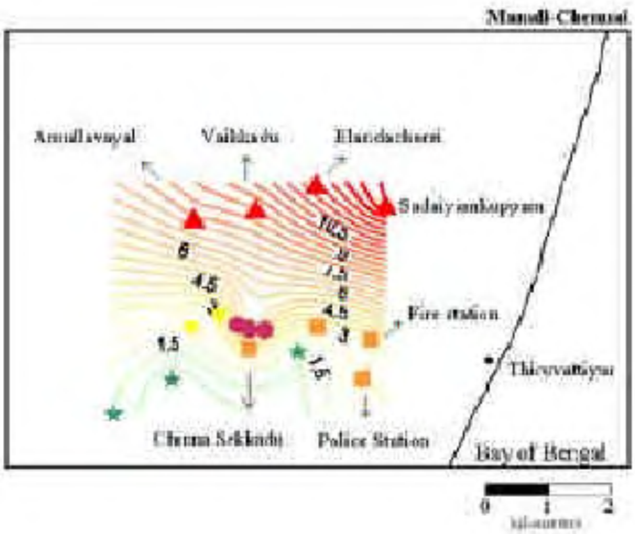

Figure 8. Women affected by asthmatic problems – survey. GPS points (symbol) – villages ▲, 8 to 15 persons affected; ●, 4 to 8 persons affected; ■, 3 to 4 persons affected; ▼ 2 to 3 persons affected; ★, 0 to 2 persons affected.

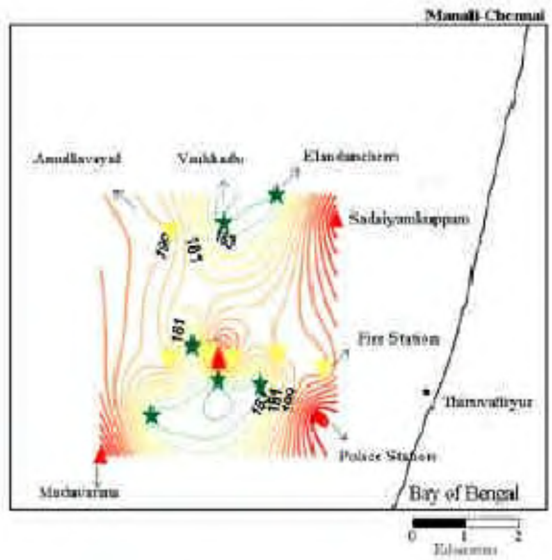

Figure 9. Medical expenses per month per head – survey. GPS points (symbol) – villages ▲, Rs 250 to 300 spent per head; ▼ Rs 200 to 250 spent per head; ★, Rs 150 to 200 spent per head.

pondents informed that 2 to 3 cases of premature deaths had occurred in Amullavayal, Vaikkadu, Elandacherri and Sadaiyankuppam. The survey result indicates that in the said villages, the urban poor people spent at the rate of Rs 150 to 200 per month per head towards cost of illness, while others spent at Rs 250 to 300 (Figure 9).

Conclusion

This is a study about higher air pollutant concentrations, which give rise to significant adverse health effects, and it is an issue of serious public health threat to inhabitants of the study area. The concentration of air pollutants, SO_2 and NO_x, is comparatively lesser than other pollutants. However, increasing levels of these pollutants, due to industrial activities and alarming increase in the number of vehicles, may become a problem in the future, with greater health impact. A comparison of the survey results of morbidity and mortality cases indicates that the impact of SPM and PM_{10} levels gives rise to increased hospitalization for respiratory, asthma and gradual increase in mortality cases. Cases of premature death due to heart attack are on the increase in male under the age group 40–59, compared to all other causes for mortality. The study concludes that the seriousness of the air pollution problem in Manali may aggravate further, if not brought under control. In this scenario, the city development and environmental enforcement authorities have to adopt future strategies to combat the menace of air pollution.

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