Assessment of the Ambient Air Quality of a Highly Industrialized Suburb of a Typical Indian City Part 1: Assessment of Quality

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Abstract A study is presented which is specific to a highly industrialized suburb of Chennai, India, but is illustrative of similar regions that are present in most large cities of India as also in other developing countries. The study area covered by us consists of a large-scale petroleum refinery and several downstream petrochemical industries situated cheek-by-jowl in a cluster called the Manali Industrial Complex. Its airshed was continuously monitored with the help of eleven ambient air quality monitoring stations, set on the basis of the wind roses of the study area in different seasons. The findings have been discussed in terms of the compatibility of the airshed with the ambient air quality standard set by India's Central Pollution Control Board.

Keywords Airshed · Ambient air quality monitoring · Pollution levels

1 Introduction

Environmental protection is one of the articles of faith of the constitution of India. In keeping with its environmental consciousness, India was among the first countries to set up a full-fledged ministry of environment (Abbasi and Abbasi 2018).

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Elaborate standards to protect the quality of air, water and soil were set and different regulatory agencies were put in place from early 1970s onwards. Over the years, more and more measures have been stipulated to check the growing levels of pollution, but how effective these measures have been? This paper presents one of the studies conducted by us to find this out.

2 The Study Area

The study area comprising of Manali Industrial Complex (MIC) and its surrounding is situated very close to the sea on the East Coast of Peninsular India, 20 km north of downtown Chennai (Fig. 1). As such, the meteorology of the area is subject to coastal effects characterized by rapid changes in wind directions and high relative humidity.

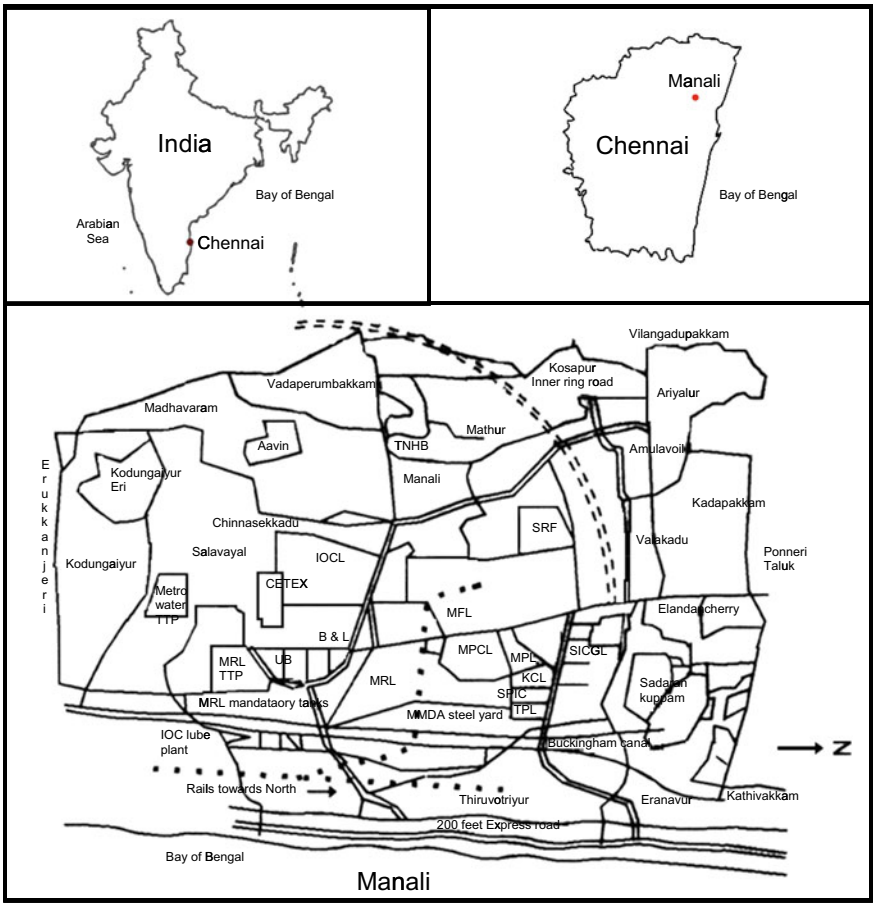

Fig. 1 Study area

At the time of performing this study, MIC had over ninety stacks of which some 63% had a height of 30–50 m, whereas 16% were 50 m or taller.

The terrain at MIC and surrounding areas is relatively flat at the mean sea level of 3.15 m. The population of the area encompassing 10 km radius from the centre of the MIC is about 5 million. It includes several populous villages engaged in the cultivation of rice, maize and ragi. The terrain is interspersed with ponds, neighbourhoods, canal and tracts of barren land. A visitor to the area is likely to notice murky plumes of emissions coming out of the stacks (Plate 1) and may even pass through a plume which might have come close to the ground. The mean roughness factor is 0.3 m. The region is semi-arid, with average annual precipitation of the order of 100–125 cm. There is sparse rainfall during the south-east monsoon (July–September) and more intense during north-east monsoon (October–November). The ambient temperatures are characteristic of humid tropics with very low diurnal variation; peak day temperatures generally hover between 32 and 37 °C, rarely falling below 30 °C except in December and January.

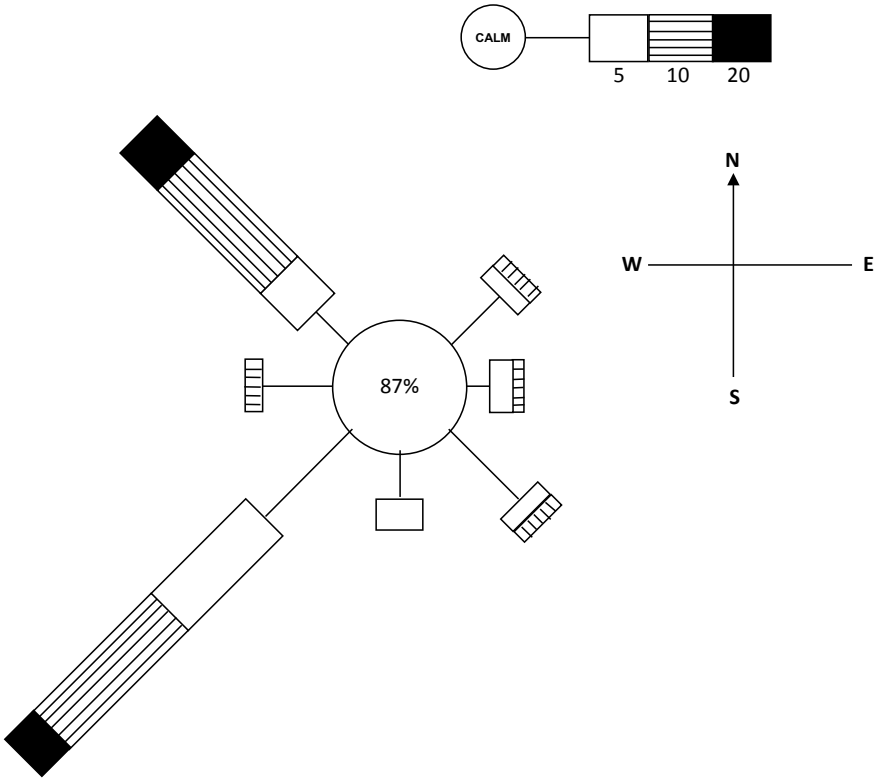

Fig. 2 Wind roses during winter

3 Wind Roses

The wind roses, drawn on the basis of meteorological data of nine-year span, are shown in Figs. 2, 3, 4 and 5.

4 Settling up of Air Quality Sampling Stations

A network of eleven sampling stations, each equipped with high-volume samplers, and concurrently operated, was set-up in and around Manali Industrial Complex (MIC) to monitor air quality. Based on wind roses, the stations were positioned to representatively monitor ambient air quality covering industrial, residential and 'sensitive' locations at various predominant wind directions throughout the year. Sampling was conducted during days as well as nights. The sampling covered four seasons: summer (March–May), pre-monsoon (June–August), monsoon (September–November) and post-monsoon or 'winter' (December–February) for two successive years. A brief description of the sampling stations is given in Table 1. The locations are depicted in Fig. 6. A noteworthy feature of this air quality study is that we have monitored chlorine and ammonia besides SPM, SO_x and NO_x.

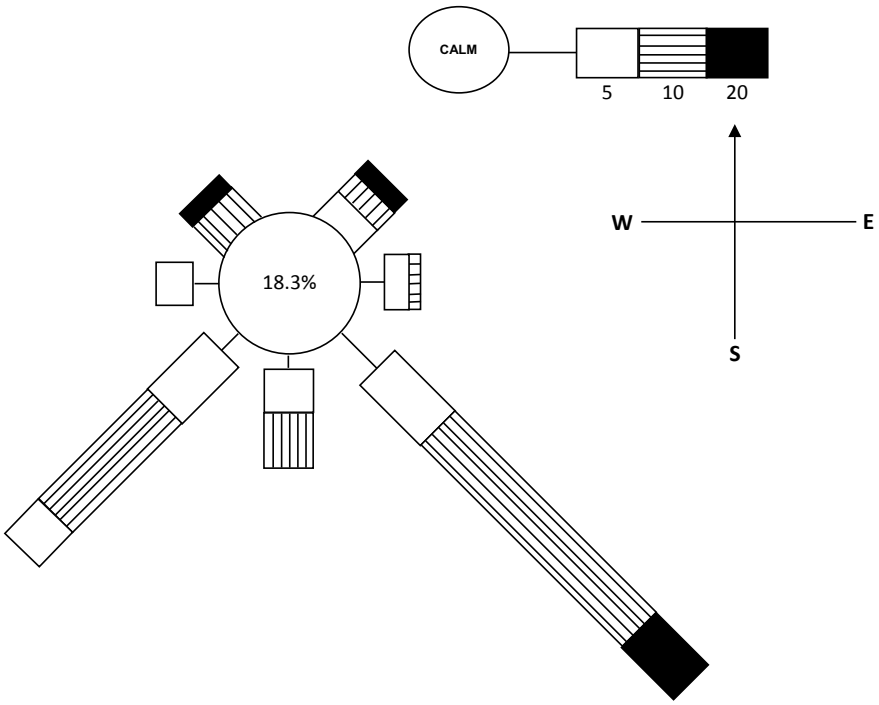

Fig. 3 Wind roses during summer

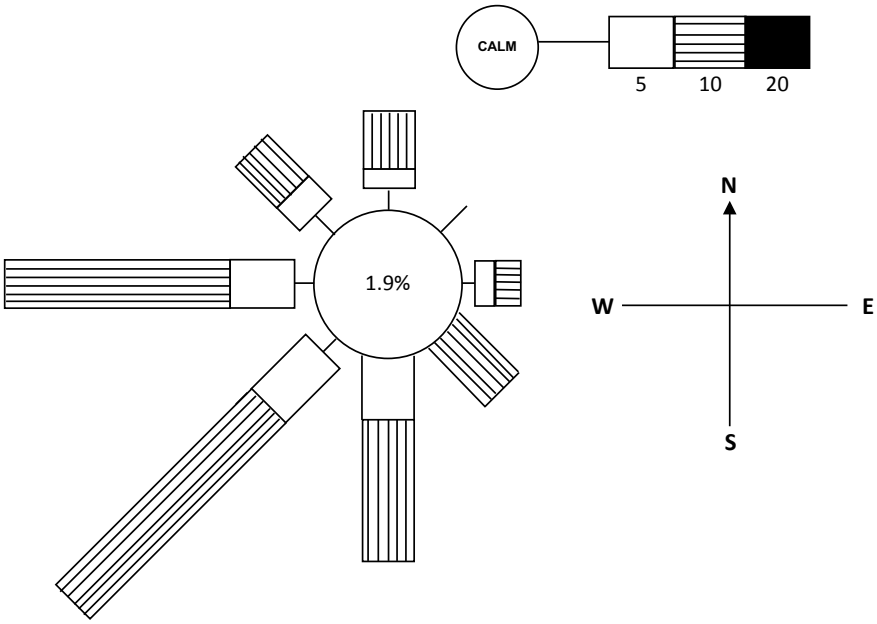

Fig. 4 Wind roses during pre-monsoons

5 Sampling and Analysis

High-volume samplers manufactured by Vayubodhan, New Delhi, were used in accordance with the procedures stipulated by the American Public Health Association (Katz 1977) and Bureau of Indian Standards. Each contiguous high-volume air sampling spanned 8 h, and three such samples were collected in succession on every sampling day, in shifts spanning 06–14 h, 14–22 h and 22–06 h. Overall, some 13,900 air samples were collected, each covering five parameters. The mode of analysis was also in strict conformity with the relevant BIS stipulations as endorsed by Central Pollution Control Board (CPCB).

Very rigorous quality control was exercised to achieve authenticity in the sampling as well as analysis (Abbasi and Abbasi 2011, 2019). To further check upon the quality of our monitoring, we had a test run, a sampling station by positioning it close to the National Ambient Air Quality Monitoring (NAAQM) station set by the Central Pollution Control Board (CPCB). Typical data generated by us, in that reconnaissance, together with the NAAQM data for the corresponding periods, are presented in Table 2. The agreement indicates that the experimental work of this team compared favourably with the CPCB findings. A note on the findings of other agencies, which had done ambient air quality surveys for preparing feasibility reports for some individual industries, is presented below.

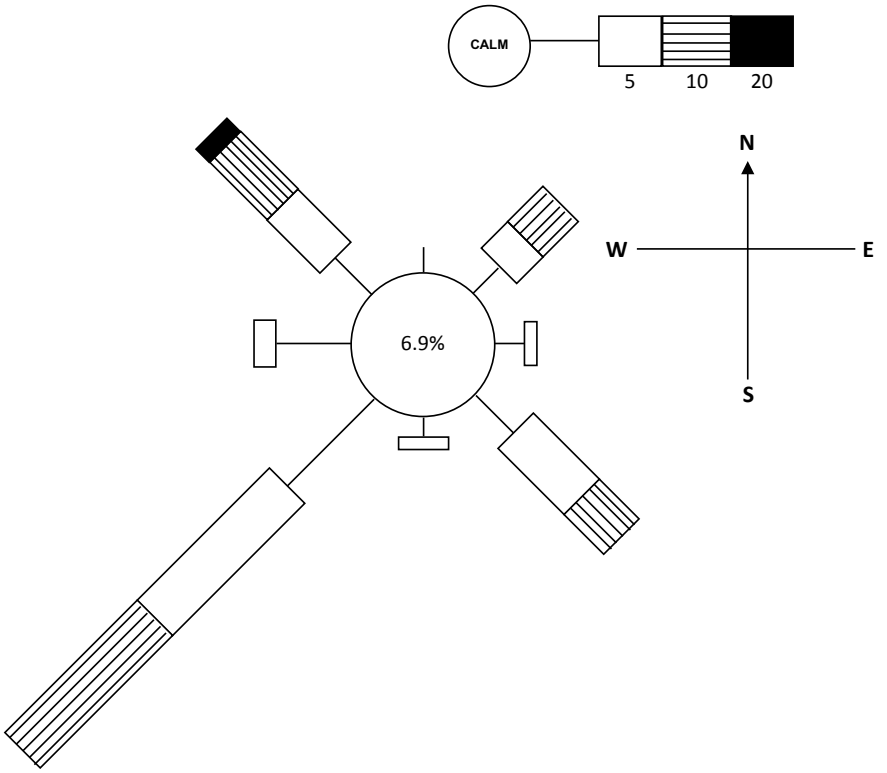

Fig. 5 Wind roses during post-monsoons

Table 1 Brief description of the sampling sites[a]

Sample No.	Sampling site	Description
MS1	Chinnasekkadu	On top of the house, backside of IOCL
MS2	Periyasekkadu	On top of the house
MS3	Manali Fire Station	On top of the office, 0.3 km from MFL
MS4	Manali school	On top of the school
MS5	TNHB (Periyamathur)	On top of the office, 0.4 km from NAPCO
MS6	Chinnamathur	On top of the house
MS7	Amulavoyal	On top of the house
MS8	Madhavaram	Open area on the ground, 3.5 km from IOCL
MS9	Vaikkadu	On top of the house
MS10	Sadayankuppam	On top of the house
MS11	Thiruvottriyur	On top of the house, 1.5 km from CPCL

[a]The samplers were placed scrupulously according to the norms, adequately above the ground level, free from lateral obstructions and local disturbances

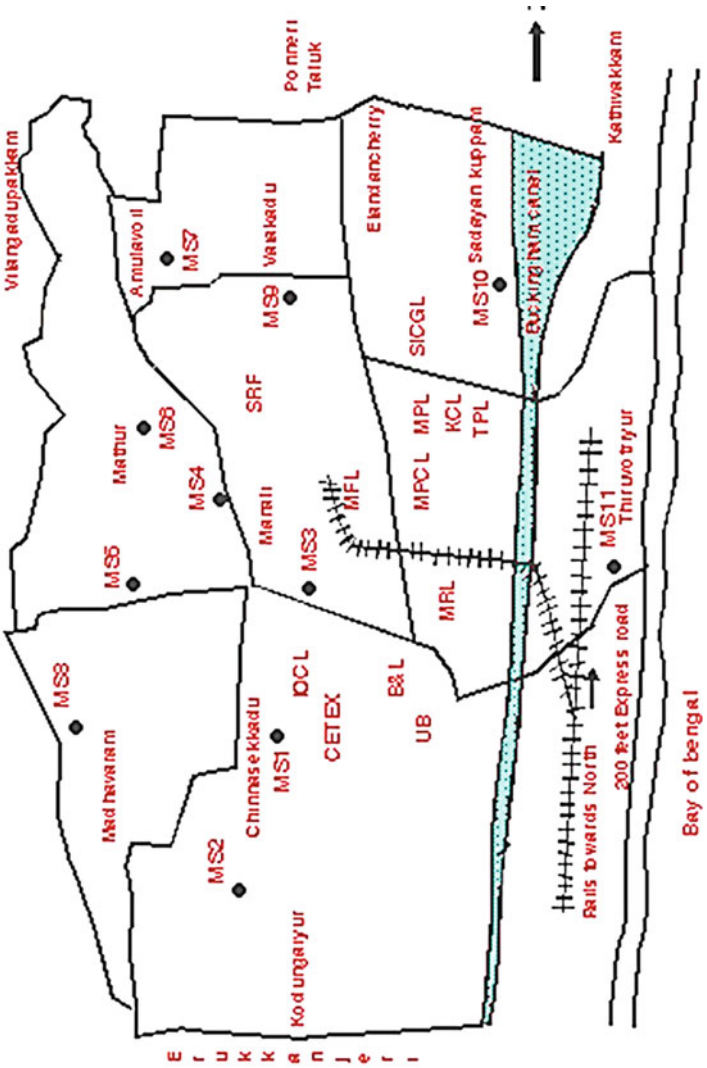

Fig. 6 Location of air quality monitoring stations [•]

Table 2 Test runs to compare the ambient air quality data generated by CPET with the NAAQM data

Sample number	SO_x, μg/m^3		NO_x, μg/m^3		SPM, μg/m^3	
	CPET	NAAQM	CPET	NAAQM	CPET	NAAQM
1	6.6	8.2	9.7	9.2	102.2	87.6
2	10.5	11.3	14.5	13.3	126.1	102.6
3	8.3	7.3	12.7	16.2	106.1	130.0
4	12.3	4.6	19.4	17.2	210.6	199.3
5	7.9	5.0	3.6	4.5	61.9	72.6
6	6.0	5.0	5.0	5.5	133.1	129.6
7	6.7	9.0	10.6	8.3	225.0	190.0
8	143.3	126.0	24.3	26.5	142.4	100.0
9	5.6	3.7	11.9	7.8	217.3	183.6
10	25.3	26.5	10.6	6.0	188.3	67.6
11	51.3	55.5	23.3	22.1	114.3	128.0
12	10.5	10.1	6.1	7.2	109.1	103.3
13	8.9	9.2	8.3	9.9	106.3	93.3
14	31.2	34.5	9.1	6.5	120.3	97.0
15	19.8	13.9	6.6	9.7	78.7	76.3
16	35.6	34.6	15.2	13.9	177.3	144.3
17	20.1	17.4	4.4	3.2	175.1	158.5
18	16.1	15.5	8.7	2.0	25.6	77.5
19	48.5	50.5	4.5	5.2	83.5	68.0

6 Existing Surveys: An Overview

In the course of examining data generated in the past by other agencies—we came across results of ambient air quality (AAQ) surveys done by a few consultancy firms in the course of preparing feasibility reports for individual industries. The findings were carefully assessed. It was seen that: (a) quite often sampling stations were located either too close to, or too far from, the emission source; (b) often the stations were not placed in predominant wind directions; and (c) appropriate standards were not always used to decide upon the fitness of ambient air. Hence, the reported work scarcely represents the airshed. Some **illustrative examples** are given below.

(i) In one of the studies, out of 14 stations set for monitoring, three were placed too close (within 0.2 km radial distance from the zone of the most dense concentration of stacks) and ten too far (more than 5 km) away. The plumes from the stacks may most often reach the ground within the area between 0.5 and 4 km radius. This positioning would miss the locations where the ambient air quality is really bad. Even then, it is seen that at station A3 10% of samples had SPM concentration more than 245 μg/m^3, thus exceeding

CPCB norms of appropriate air quality (as per which 2% of the samples should not have higher than permissible level of any pollutant). Likewise, in another study, four stations were placed for AAQ monitoring, out of which one was too close and one too far away.

(ii) Quite often, the samplers were not placed on the basis of wind directions. For example in the study mentioned above during September–October, the predominant wind direction is SW, but only two stations (A1 and A7) out of seven locations monitored during that season were in the downwind direction. The remaining five stations were either upwind or in the crosswind direction as shown in Fig. 7. Similarly in the other study, only one station was in downwind direction out of four stations monitored during all the four seasons. During pre-monsoon and monsoon seasons, the predominant wind direction is SW, but except the location MA5 all other samplers were in either upwind or crosswind directions as shown in Fig. 8.

(iii) To assess the pollution level, most of the agencies have used only the permissible limit for industrial zone and have calculated the percentage of samples polluted solely on that basis. But for AAQ stations located in residential or 'sensitive' locations, appropriate standards set for those types of locations ought to have been used. In a typical study, most of the samples exceeded the limit for SPM set for residential areas at locations A2–A7. The percentage of samples found polluted were 70% in A2, 16% in A3, 50% in A4, 50% in A5 and 70% in A7 (Table 3-4A; page 3.22) of the said report. In another study, it was reported that all the samples were within CPCB limits which are not really so. For example, in the following places during summer the percentage of samples exceeded the prescribed limits for residential areas: Manali village (>90%), Sathangadu (>90%), Redhills (>90%), Kadapakkam (>90%), Thiruvottriyur (>75%), Ennore school (>75%), Sadayankuppam (>50%), Vadaperumbakkam (>50%) and Jyothinagar (>20%).

Therefore, we believe, an extensive ambient air quality survey, as done and now being reported by us, was necessary to accurately gauge the impact of the Manali Industrial Complex on the airshed of the study area.

7 Results and Discussion

The experiments have led to data on the ambient air quality in terms of concentrations of five different parameters in three different samples over each 24-h span, taken during days as well as nights, at eleven different locations and in four different seasons. This all adds to a very large body of basic data which the authors can provide on request. Here, to resolve this enormous mass of information into an easy-to-comprehend and easy-to-interpret form, all the data have been processed in terms of the compliance of different individual parameters and different total samples with the relevant National Ambient Air Quality (NAAQ) Standards.

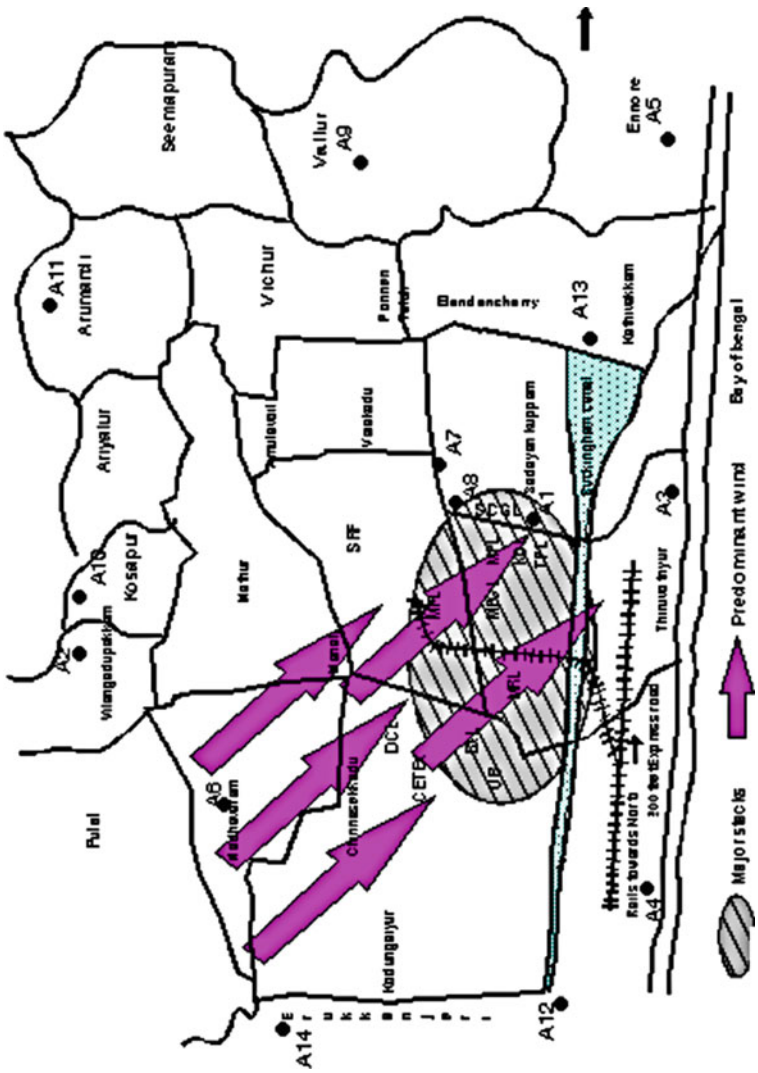

Fig. 7 Illustrative example of improper positioning of sampling locations with respect to predominant wind directions during pre-monsoon and monsoon: example I

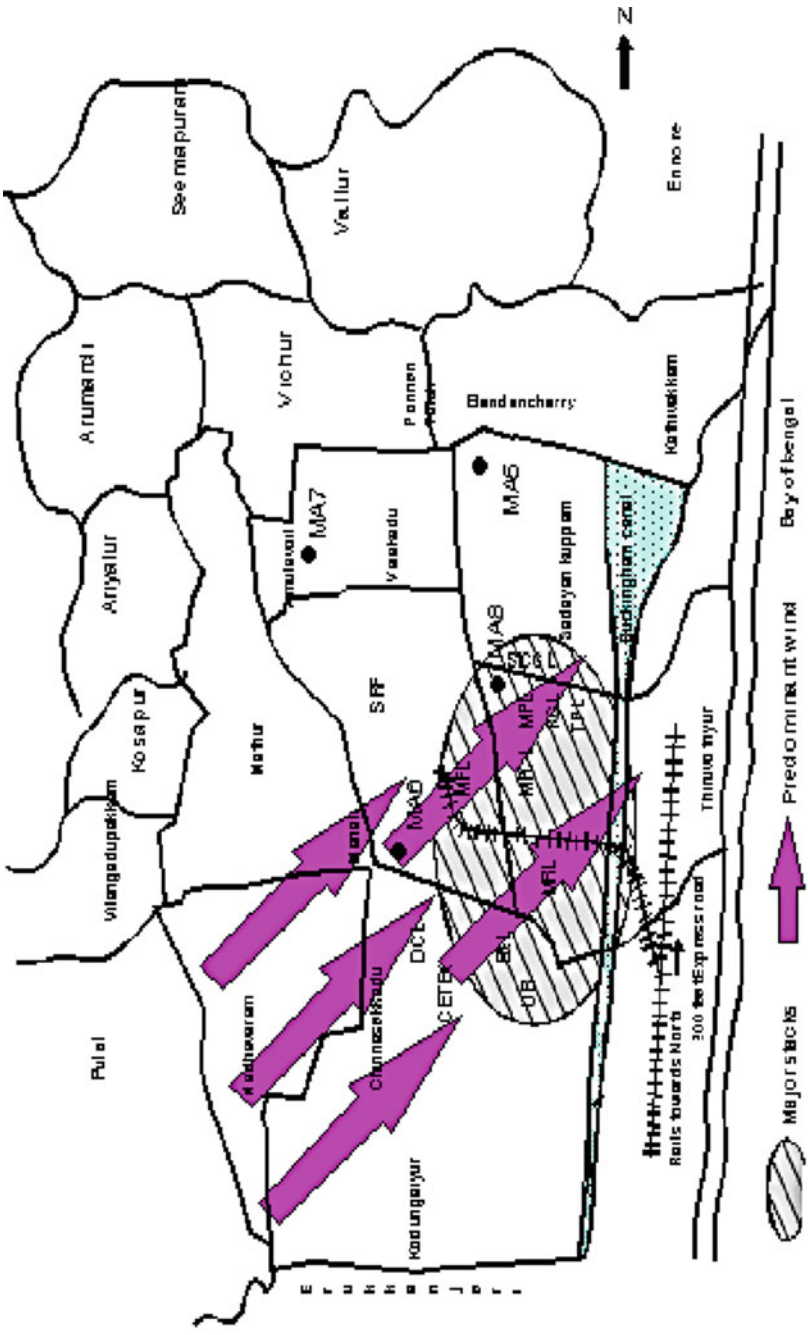

Fig. 8 Illustrative example of improper positioning of sampling locations with respect to predominant wind directions during pre-monsoon and monsoon: example II

Table 3 National Ambient Air Quality Standards as per Air Act and EPA Notification GSR 176 E of 2 April 1996 (Abbasi and Abbasi 2018)

Pollutant[a]	Concentration in ambient air, μg/m^3		
	Sensitive location	Residential, rural and other	Industrial
SO_x	30	80	120
NO_x	30	80	120
SPM	100	200	500
Ammonia	@	@	@
Chlorine	@	@	@

[a]24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time it may exceed but not on two consecutive days
@The standards for these two have not been announced as yet

The standards are summarized in Table 3. As per Central Pollution Control Board (CPCB) norms, a location is considered polluted if 24 hourly/8 hourly air quality values exceed the relevant standard in more than 2% of the samples (CPCB 2012; Abbasi and Abbasi 2018).

7.1 Studies on SO_x

7.1.1 SO_x: Pre-monsoon

As may be seen from Table 3, the National Ambient Air Quality Standards for SO_x are: 120 μg/m^3 for industrial locations, 80 μg/m^3 for residential or rural locations and 30 μg/m^3 for sensitive locations. Further, as per the norms of CPCB, these standards should not exceed in the relevant locations for more than 2% of the samples in a year.

But, as is revealed from Table 4, in ten of the eleven stations, the air quality is unacceptable vis-a-vis SO_x, as in more than 2% of the samples the SO_x levels are higher than the standards applicable to industrial location.

However, the study area also encompasses residential locations as also 'sensitive' locations such as schools and hospitals (primary health centres). When we apply the air quality standards appropriate to such locations, it is revealed that in all the eleven stations, the CPCB norms (of not more than 2% samples exceeding the prescribed limits) are surpassed. The extent of SO_x pollution in terms of compliance with residential or sensitive locations is most marked at the sampling stations situated at Chinnamathur, TNHB, Madhavaram and Vaikkadu where more than half the samples exceed the prescribed limits. In terms of the standards for sensitive locations, which are the most stringent, the non-compliance of the air samples is even more marked: 88.7% samples exceed his limit at Periyasekkadu, followed by 85.6% at Chinnamathur and 81.7% at TNHB.

Table 4 Percentage of samples polluted during pre-monsoon

S. No.	Location	Samples during	% of samples polluted											
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
1	Chinnasekkadu	Day	5.7	24.5	56.6	0.0	0.0	34.0	0.0	17.0	41.5	5.7	34.0	66.0
		Night	7.5	30.2	66.0	0.0	0.0	37.7	0.0	22.6	47.2	7.5	41.5	73.6
		Total	6.6	27.4	61.3	0.0	0.0	35.8	0.0	19.8	44.3	6.6	37.7	69.8
2	Periyasekkadu	Day	7.5	22.6	86.8	0.0	0.0	41.5	0.0	18.9	41.5	7.5	28.3	88.7
		Night	7.5	24.5	90.6	0.0	0.0	50.9	0.0	30.2	52.8	7.5	32.1	94.3
		Total	7.5	23.6	88.7	0.0	0.0	46.2	0.0	24.5	47.2	7.5	30.2	91.5
3	Manali Fire Station	Day	0.0	7.5	66.0	0.0	7.5	71.7	1.9	52.8	84.9	1.9	56.6	84.9
		Night	0.0	22.6	79.2	0.0	1.9	77.4	0.0	58.5	90.6	0.0	62.3	94.3
		Total	0.0	15.1	72.6	0.0	4.7	74.5	0.9	55.7	87.7	0.9	59.4	89.6
4	Manali School	Day	24.5	37.7	71.7	0.0	0.0	28.3	0.0	24.5	50.9	24.5	56.6	83.0
		Night	18.9	28.3	60.4	0.0	0.0	22.6	0.0	18.9	41.5	18.9	39.6	67.9
		Total	21.7	33.0	66.0	0.0	0.0	25.5	0.0	21.7	46.2	21.7	48.1	75.5
5	TNHB	Day	17.3	53.8	76.9	0.0	0.0	34.6	0.0	25.0	69.2	17.3	61.5	82.7
		Night	23.1	69.2	86.5	0.0	0.0	48.1	0.0	34.6	75.0	23.1	73.1	86.5
		Total	20.2	51.2	81.7	0.0	0.0	41.3	0.0	29.8	72.1	20.2	67.3	84.6
6	Chinnamathur	Day	21.2	48.1	82.7	0.0	0.0	50.0	0.0	11.5	78.8	21.2	53.8	86.5
		Night	26.9	57.7	88.4	0.0	0.0	73.1	0.0	25.0	82.7	26.9	59.6	92.3
		Total	24.0	52.9	85.6	0.0	0.0	61.5	0.0	18.3	80.8	24.0	56.7	89.4
7	Amulavoyal	Day	9.4	41.5	54.7	0.0	0.0	30.1	0.0	39.6	49.1	9.4	47.2	62.3
		Night	15.1	45.3	62.3	0.0	0.0	35.8	0.0	34.0	47.2	15.1	52.8	73.6
		Total	12.3	43.4	58.5	0.0	0.0	33.0	0.0	36.8	48.1	12.3	50.0	67.9

(continued)

Table 4 (continued)

S. No.	Location	Samples during	% of samples polluted										
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
8	Madhavaram	Day	3.8	48.1	57.7	0.0	0.0	40.4	0.0	23.1	48.1	3.8	61.5	73.1
		Night	11.5	53.8	73.1	0.0	0.0	34.6	0.0	28.8	53.8	11.5	69.2	76.9
		Total	7.7	51.0	65.4	0.0	0.0	37.5	0.0	26.0	51.0	7.7	65.4	75.0
9	Vaikkadu	Day	11.3	49.1	73.6	0.0	0.0	32.1	0.0	34.0	56.6	11.3	54.7	79.2
		Night	17.0	54.7	79.2	0.0	0.0	39.6	0.0	35.8	66.0	17.0	60.4	81.1
		Total	14.2	51.9	76.4	0.0	0.0	35.8	0.0	34.9	61.3	14.2	57.5	80.2
10	Sadayankuppam	Day	5.7	34.0	56.6	0.0	0.0	34.0	0.0	22.6	47.2	5.7	37.7	60.4
		Night	11.3	39.6	66.0	0.0	0.0	35.8	0.0	18.9	52.8	11.3	43.4	67.9
		Total	8.5	36.8	61.3	0.0	0.0	34.9	0.0	20.8	50.0	8.5	45.6	64.2
11	Thiruvottriyur	Day	18.9	43.4	60.4	0.0	0.0	37.7	0.0	28.3	56.6	18.9	52.8	66.0
		Night	13.2	37.7	56.6	0.0	0.0	30.2	0.0	24.5	49.1	13.2	49.1	60.4
		Total	16.0	45.6	58.5	0.0	0.0	34.0	0.0	26.4	52.8	16.0	50.9	63.2

7.1.2 SO_x: Monsoon

During 'monsoon' (September–November), too, all but one sampling station has recorded unacceptable air quality as per NAAQ Standards of SO_x levels and the CBCB norm of a number of above-limit samples tolerable at a given location (Table 5). The most liberal of the three standards, applicable to industrial locations, is exceeded to the extent of ~38% at Manali Fire Station and Amulavoyal. At Vaikkadu and TNHB, the non-compliance is in 25 and 21.4% of the samples, respectively. The residential/rural and sensitive locations in the study area receive unacceptable SO_x levels much more frequently, as reflected in the high percentage of samples exceeding the limits set for such locations at all but one of the stations.

7.1.3 SO_x: Post-monsoon (or 'Winter')

The SO_x levels are generally lesser during the post-monsoon months (December–February) due, perhaps, to the generally more unstable atmospheric conditions in these months enabling quicker dispersion of pollutants than in the pre-monsoon and monsoon months of June–November when often the sky is overcast with lesser movements of air. Even then, the fraction of samples found polluted (Table 6) as per the standards for industrial locations exceed CPCB norms at nine of the stations. In terms of the standards applicable to residential/rural locations and sensitive locations, the non-compliance is more blatant even though lesser in magnitude than in the previous two seasons.

7.1.4 SO_x: Summer

The summer (March–May) in the study area is characterized by increasing ambient temperatures and correspondingly increasing relative humidity (Table 7). Further, the effect of south-west monsoon settling in the west of the Western Ghats off-and-on spills over to the study area which is situated east of the Ghats, resulting in cloudy skies. These factors may combine to create a less favourable climate for the dispersion of air pollutants than was possible in the preceding months, assuming that all other factors—especially the source strength—had remained constant.

During this study, the air quality with reference to SO_x in summer has, expectedly, deteriorated. All the eleven sampling stations reflect air quality which is unacceptable vis-a-vis SO_x levels as per the CPCB norms. The impact at Chinnasekkadu, Manali School and Amulavoyal is particularly severe. In three other stations (Periyasekkadu, TNHB and Chinnamathur), too, 20% or more samples have SO_x levels higher than permissible for industrial locations. In terms of standards for residential/commercial and sensitive locations, the proportion of polluted samples is even higher; the situation at Chinnasekkadu, Periyasekkadu, Manali School, TNHB, Chinnamathur and Amulavoyal is being particularly bad.

Table 5 Percentage of samples polluted during monsoon

S. No.	Location	Samples during	% of samples polluted											
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
1	Chinnasekkadu	Day	5.8	38.5	84.5	0.0	0.0	38.4	0.0	26.9	73.1	5.8	48.1	90.3
		Night	11.8	47.1	94.1	0.0	0.0	43.1	0.0	35.3	84.3	11.8	54.9	94.1
		Total	8.7	42.7	89.3	0.0	0.0	40.7	0.0	31.1	78.6	8.7	51.4	92.2
2	Periyasekkadu	Day	9.6	42.3	76.9	0.0	0.0	34.6	0.0	23.1	61.5	9.6	53.8	84.6
		Night	15.7	47.1	84.3	0.0	0.0	39.2	0.0	29.4	68.6	15.7	58.8	94.1
		Total	12.6	44.7	80.6	0.0	0.0	36.9	0.0	26.2	65.0	12.6	56.3	89.3
3	Manali Fire Station	Day	0.0	5.8	36.5	0.0	0.0	17.6	0.0	30.1	57.7	0.0	34.6	76.9
		Night	0.0	17.6	58.8	0.0	0.0	19.6	0.0	49.0	62.7	0.0	58.8	90.2
		Total	0.0	11.7	47.6	0.0	0.0	18.4	0.0	39.8	60.2	0.0	46.6	83.5
4	Manali School	Day	34.6	38.5	100	0.0	0.0	11.5	0.0	23.1	67.3	34.6	50.0	100
		Night	43.1	58.8	100	0.0	0.0	19.6	0.0	19.6	78.4	58.8	60.8	100
		Total	38.8	48.5	100	0.0	0.0	15.5	0.0	21.4	72.8	46.6	55.3	100
5	TNHB	Day	19.2	69.2	90.4	0.0	0.0	59.6	0.0	34.6	73.1	19.2	73.1	94.2
		Night	23.5	78.4	96.1	0.0	0.0	68.6	0.0	41.2	88.2	23.5	84.3	98.0
		Total	21.4	73.8	93.2	0.0	0.0	64.1	0.0	37.9	80.6	21.4	78.6	96.1
6	Chinnamathur	Day	11.5	19.2	28.8	0.0	0.0	7.7	0.0	21.1	25.0	11.5	28.8	34.6
		Night	15.7	25.5	35.2	0.0	0.0	15.7	0.0	19.6	29.4	15.7	35.3	39.2
		Total	13.5	22.3	32.0	0.0	0.0	11.7	0.0	20.4	27.2	13.5	32.0	36.9
7	Amulavoyal	Day	30.8	67.3	84.6	0.0	0.0	15.3	0.0	23.1	86.5	30.8	71.1	92.3
		Night	46.2	92.3	100	0.0	0.0	23.1	0.0	44.2	100	46.2	96.2	100
		Total	38.5	79.8	92.3	0.0	0.0	19.4	0.0	33.7	93.3	38.5	83.7	96.2

(continued)

Table 5 (continued)

S. No.	Location	Samples during	% of samples polluted										
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
8	Madhavaram	Day	3.8	38.5	69.2	0.0	0.0	53.8	0.0	30.8	73.1	3.8	48.1	76.9
		Night	9.8	45.1	78.4	0.0	0.0	58.8	0.0	33.3	82.4	9.8	54.9	88.2
		Total	6.8	41.7	73.8	0.0	0.0	56.3	0.0	32.0	77.7	6.8	51.5	82.5
9	Vaikkadu	Day	23.1	53.8	96.2	0.0	0.0	11.5	0.0	23.1	57.7	23.1	59.6	96.2
		Night	26.9	57.7	100	0.0	0.0	23.1	0.0	34.6	67.3	26.9	71.2	100
		Total	25.0	55.8	98.1	0.0	0.0	17.3	0.0	28.8	62.5	25.0	65.4	98.1
10	Sadayankuppam	Day	9.6	48.1	76.9	0.0	0.0	19.2	0.0	28.8	73.1	9.6	53.8	84.6
		Night	13.5	55.7	86.5	0.0	0.0	15.4	0.0	30.8	76.9	13.5	61.5	88.5
		Total	11.5	51.9	81.7	0.0	0.0	17.3	0.0	29.8	75.0	11.5	57.6	86.5
11	Thiruvottriyur	Day	7.7	28.8	42.3	0.0	0.0	34.6	0.0	23.1	36.5	7.7	34.6	50.0
		Night	3.8	23.1	38.5	0.0	0.0	28.8	0.0	19.2	38.5	3.8	30.8	42.3
		Total	5.8	26.0	40.4	0.0	0.0	31.7	0.0	37.5	37.5	5.8	32.7	46.2

Table 6 Percentage of samples polluted during post-monsoon

S. No.	Location	Samples during	% of samples polluted											
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
1	Chinnasekkadu	Day	19.2	48.1	57.7	0.0	0.0	38.5	0.0	25.0	42.3	19.2	53.8	61.5
		Night	11.5	57.7	67.3	0.0	0.0	19.2	0.0	28.8	48.1	11.5	67.3	73.1
		Total	15.4	52.9	62.5	0.0	0.0	28.8	0.0	26.9	45.4	15.4	60.6	67.3
2	Periyasekkadu	Day	9.6	44.2	53.8	0.0	0.0	28.8	0.0	24.0	73.1	9.6	50.0	76.9
		Night	15.4	50.0	57.7	0.0	0.0	38.5	0.0	28.8	71.2	15.4	73.1	80.8
		Total	12.5	47.1	55.8	0.0	0.0	33.7	0.0	26.9	72.1	12.5	61.5	78.8
3	Manali Fire Station	Day	9.6	15.4	34.6	0.0	0.0	19.2	0.0	19.2	57.7	9.6	28.8	80.8
		Night	7.7	9.6	38.5	0.0	0.0	9.6	0.0	21.2	61.5	7.7	23.1	69.2
		Total	8.7	12.7	36.5	0.0	0.0	14.4	0.0	20.2	59.6	8.7	26.0	75.0
4	Manali School	Day	3.8	17.3	75.0	0.0	0.0	38.5	0.0	57.7	100	3.8	65.4	100
		Night	19.2	38.5	80.8	0.0	0.0	23.1	0.0	67.3	96.2	19.2	61.5	96.2
		Total	11.5	27.9	77.9	0.0	0.0	30.8	0.0	62.5	98.1	11.5	63.5	98.1
5	TNHB	Day	0.0	9.6	38.5	0.0	0.0	63.5	0.0	26.9	61.5	0.0	30.5	92.3
		Night	11.5	19.2	48.1	0.0	0.0	67.3	0.0	30.8	69.2	11.5	44.2	84.6
		Total	5.8	14.4	43.3	0.0	0.0	65.4	0.0	28.8	65.4	5.8	37.5	88.5
6	Chinnamathur	Day	11.5	38.5	67.3	0.0	0.0	28.8	0.0	28.8	61.5	11.5	48.1	73.1
		Night	15.4	48.1	76.9	0.0	0.0	30.8	0.0	32.7	76.9	15.4	53.8	86.5
		Total	13.5	43.3	72.1	0.0	0.0	29.8	0.0	30.8	69.2	13.5	51.0	79.8
7	Amulavoyal	Day	0.0	23.5	54.9	0.0	0.0	19.6	0.0.	15.7	39.2	0.0	25.5	68.6
		Night	0.0	27.5	58.8	0.0	0.0	29.4	0.0	13.7	49.0	0.0	31.4	78.4
		Total	0.0	25.5	56.9	0.0	0.0	24.5	0.0	14.7	44.1	0.0	28.4	73.5

(continued)

Table 6 (continued)

S. No.	Location	Samples during	% of samples polluted											
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
8	Madhavaram	Day	11.5	48.1	57.6	0.0	0.0	48.1	0.0	5.8	67.3	11.5	51.9	67.3
		Night	9.6	53.8	61.5	0.0	0.0	46.2	0.0	3.8	57.7	9.6	53.8	61.5
		Total	10.6	51.0	59.6	0.0	0.0	47.1	0.0	4.8	62.5	10.6	52.9	64.4
9	Vaikkadu	Day	0.0	27.5	39.2	0.0	0.0	45.1	0.0	21.6	39.2	0.0	31.4	54.9
		Night	0.0	31.4	47.1	0.0	0.0	43.1	0.0	23.5	41.2	0.0	39.2	58.8
		Total	0.0	29.4	43.1	0.0	0.0	44.1	0.0	22.5	40.2	0.0	35.3	56.9
10	Sadayankuppam	Day	5.9	31.4	58.8	0.0	0.0	29.4	0.0	19.6	39.2	5.9	35.3	62.7
		Night	11.8	39.2	64.7	0.0	0.0	33.3	0.0	23.5	49.0	11.8	39.2	68.7
		Total	8.8	35.3	61.8	0.0	0.0	31.4	0.0	21.6	44.1	8.8	37.3	65.7
11	Thiruvottriyur	Day	2.0	2.0	49.0	0.0	0.0	39.2	0.0	15.7	41.2	2.0	25.5	54.9
		Night	3.9	3.9	35.3	0.0	0.0	29.4	0.0	15.7	35.3	3.9	23.5	39.2
		Total	2.9	2.9	42.2	0.0	0.0	34.3	0.0	15.7	38.2	2.9	24.5	47.1

Table 7 Percentage of samples polluted during summer; the columns of I, R and S represent samples polluted as per norms for industrial, residential and sensitive locations, respectively

S. No.	Location	Samples during	% of samples polluted											
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
1	Chinnasekkadu	Day	28.3	52.8	100	0.0	3.7	52.8	0.0	22.6	66.0	28.3	60.4	100
		Night	34.6	67.3	100	0.0	7.7	57.7	0.0	25.0	71.2	34.6	73.1	100
		Total	31.4	60.0	100	0.0	5.7	55.2	0.0	23.8	68.6	31.4	66.7	100
2	Periyasekkadu	Day	18.9	37.7	94.3	0.0	0.0	49.1	0.0	22.6	90.6	18.9	41.5	96.2
		Night	23.1	48.1	98.1	0.0	1.9	55.8	0.0	30.8	100	23.1	53.8	100
		Total	21.0	42.9	96.2	0.0	1.0	52.4	0.0	26.7	95.2	21.0	47.6	98.1
3	Manali Fire Station	Day	37.7	66.0	90.6	0.0	11.5	66.0	0.0	37.7	52.8	37.7	79.2	94.3
		Night	34.6	69.2	86.5	0.0	0.0	53.8	0.0	34.6	50.0	34.6	73.1	90.4
		Total	36.2	67.6	88.6	0.0	5.7	60.0	0.0	36.2	51.4	36.2	84.6	92.4
4	Manali School	Day	7.5	28.3	75.5	0.0	0.0	66.0	0.0	37.7	86.8	7.5	41.5	94.3
		Night	3.8	19.2	73.1	0.0	0.0	57.7	0.0	30.8	80.8	3.8	30.8	92.4
		Total	5.7	23.8	74.3	0.0	0.0	61.9	0.0	34.3	83.8	5.7	36.2	93.3
5	TNHB	Day	26.9	57.7	100	0.0	0.0	50.0	0.0	0.0	76.9	26.9	57.7	100
		Night	15.4	50.0	96.2	0.0	1.9	48.1	0.0	0.0	82.7	15.4	50.0	100
		Total	21.2	53.8	98.1	0.0	1.0	49.0	0.0	0.0	79.8	21.2	53.8	100
6	Chinnamathur	Day	23.1	48.1	92.3	0.0	0.0	38.5	0.0	13.5	50.0	23.1	57.7	100
		Night	26.9	51.9	100	0.0	3.8	50.0	0.0	19.2	67.3	26.9	67.3	100
		Total	25.0	50.0	96.2	0.0	1.9	44.2	0.0	16.3	58.7	25.0	62.5	100
7	Amulavoyal	Day	24.5	49.1	84.9	0.0	0.0	47.2	0.0	11.3	50.9	24.5	56.6	92.5
		Night	38.5	73.1	100	0.0	0.0	57.7	0.0	23.1	65.4	38.5	73.1	100
		Total	31.4	61.0	92.4	0.0	0.0	52.4	0.0	17.1	58.1	31.4	64.8	96.2

(continued)

Table 7 (continued)

S. No.	Location	Samples during	% of samples polluted										
			SO_x			NO_x			SPM			Overall quality		
			I	R	S	I	R	S	I	R	S	I	R	S
8	Madhavaram	Day	3.8	38.4	53.8	0.0	0.0	48.1	0.0	9.6	48.1	3.8	42.3	57.7
		Night	5.8	34.6	57.7	0.0	0.0	53.8	0.0	15.4	53.8	5.8	46.2	61.5
		Total	4.8	36.5	55.8	0.0	0.0	51.0	0.0	12.5	51.0	4.8	44.2	59.6
9	Vaikkadu	Day	7.5	39.6	60.4	0.0	0.0	34.0	0.0	22.6	52.8	7.5	45.3	64.2
		Night	11.5	44.2	76.9	0.0	0.0	44.2	0.0	28.8	67.3	11.5	53.8	80.8
		Total	9.5	41.9	68.6	0.0	0.0	39.0	0.0	25.7	60.0	9.5	49.5	72.4
10	Sadayankuppam	Day	3.8	18.9	47.2	0.0	0.0	32.1	0.0	7.5	37.7	3.8	22.6	52.8
		Night	5.8	28.8	50.0	0.0	0.0	34.6	0.0	15.4	48.1	5.8	34.6	57.7
		Total	4.8	23.8	48.6	0.0	0.0	33.3	0.0	11.4	42.9	4.8	28.6	55.7
11	Thiruvottriyur	Day	9.4	37.7	66.0	0.0	0.0	69.8	0.0	5.7	47.2	9.4	39.6	71.7
		Night	15.4	34.6	57.7	0.0	0.0	61.5	0.0	1.9	46.2	15.4	34.6	67.3
		Total	12.4	36.2	61.9	0.0	0.0	65.7	0.0	3.8	46.7	12.4	37.1	69.5

7.2 Studies on NO_x

NO_x is not a pollutant of as serious concern in the study area as is SO_x. In none of the samples NO_x levels that were higher than permissible for industrial locations, have been recorded. During the monsoon and post-monsoon seasons, NO_x is within acceptable levels for residential/commercial locations as well (Tables 4, 5, 6 and 7). Only during summer, Chinnasekkadu and Manali School and during post-monsoon Manali School stations receive NO_x levels higher than permissible for residential/ rural locations. The possible reason for NO_x levels being significantly lower than SO_x levels is that the former is generally contributed by vehicular exhaust and the traffic density in the study area is not excessively high. Hence, the prime contributor to ambient air pollution is industrial emissions.

7.3 Studies on SPM

At all sampling stations, except one—that too in only one of the four seasons studied—SPM levels are higher than permissible for residential/commercial or 'sensitive' locations (Tables 4, 5, 6 and 7). The sole exception is TNHB during summer. This is an exceedingly undesirable situation as several densely populated villages and other residential areas lie within the impact area studied by us. The area also contains sensitive locations such as schools and primary health centres. Indeed, some of the highest SPM levels have been recorded at Manali School, during pre-monsoon (Table 4), when more than half the samples exceeded the standards for residential/ rural locations and 87.7% samples exceed the standards for 'sensitive' location (which, by definition, Manali School is). The school has also recorded unacceptable SPM levels during all other seasons (Tables 4, 5, 6 and 7). Among other stations seriously affected by SPM levels, higher than permissible for residential/commercial locations are Manali Fire Station (especially during the post-monsoon months), Chinnasekkadu and Periyasekkadu (all year round), Amulavoyal (especially during pre-monsoon and monsoon) and Vaikkadu (more than 22% samples polluted all year round). The sensitive locations receive unacceptable SPM levels even more frequently, over half the time in the majority of cases.

7.4 Overall Air Quality

The gist of the entire ambient air quality survey is presented in Table 8. This table has been culled from the raw data provided in Abbasi et al. (2013). It may be seen that only at one of the eleven sampling locations—Manali Fire Station—the air pollution was within the acceptable limits set by CPCB during pre-monsoon and

Table 8 Air samples (%) found polluted in and around Manali Industrial Complex

Stations	Season											
	Post-monsoon, %			Summer, %			Pre-monsoon, %			Monsoon, %		
	Day	Night	Total	Day	Night	Total	Day	Night	Total	Day	Night	Total
Chinnasekkadu	53.8	67.3	60.6	60.4	73.1	66.7	34.0	41.5	37.7	48.1	54.9	51.4
Periyasekkadu	50.0	73.1	61.5	41.5	53.8	47.6	28.3	32.1	30.2	53.8	58.8	56.3
Manali School	100.0	96.2	98.1	94.3	90.4	92.4	83.0	67.9	75.5	100.0	100.0	100.0
Manali Fire Station	9.6	7.7	8.7	7.5	3.8	5.7	1.9	0.0	0.9	0.0	0.0	0.0
TNHB	30.8	44.2	37.5	57.7	50.0	53.8	61.5	73.1	67.3	73.1	84.3	78.6
Chinnamathur	48.1	53.8	51.0	57.7	67.3	62.5	53.8	59.6	56.7	28.8	35.3	32.0
Amulavoyal	25.5	31.4	28.4	56.6	73.1	64.8	47.2	52.8	50.0	71.1	96.2	83.7
Madhavaram	51.9	53.8	52.9	42.3	46.2	44.2	61.5	69.2	65.4	48.1	54.9	51.5
Vaikkadu	31.4	39.2	35.3	45.3	53.8	49.5	54.7	60.4	57.5	59.6	71.2	65.4
Sadayankuppam	35.3	39.2	37.3	22.6	34.6	28.6	37.7	43.4	45.6	53.8	61.5	57.6
Thiruvottriyur	25.5	23.5	24.5	39.6	34.6	37.1	52.8	49.1	50.9	34.6	30.8	32.7

monsoon seasons. At all other sampling locations and in all seasons, the air was polluted above the said norms.

The airshed patterns are further illustrated in Figs. 9, 10 and 11. In summary:

(a) During pre-monsoon, high concentrations of air pollutants are observed in the sampling stations situated in the north-east direction. The isoconcentration profiles for SO_x and SPM (Figs. 9 and 10) indicate pollutant levels far above the limits permitted by Central Pollution Control Board (CPCB) and encompass residential areas such as Sadayankuppam, Amulavoyal and Vaikkadu.
(b) Incidence of high concentration of NO_x is limited to a relatively smaller area.
(c) In the post-monsoon months, the concentration contours for SO_x (Fig. 11) over the residential areas of Manali, Chinnasekkadu, Periyasekkadu, Madhavaram and Selavayal indicated levels exceeding the prescribed limits of CPCB.
(d) During the post-monsoon months, the concentrations of NO_x and SO_x are lower, compared to the pre-monsoon, yet these concentrations are above CPCB's prescribed limits.
(e) In monsoon, the isopleths for SO_x indicate that the pollutant levels exceed the CPCB standards. They envelop wider area than in other seasons, including residential areas of Manali, Chinnasekkadu, Sadayankuppam, Amulavoyal and Vaikkadu.
(f) During summer, the rate of aerial dilution appears to be maximum, and concentrations of the pollutants are lower compared to any other seasons. Even then, the concentrations of SO_x are higher than the CPCB's prescribed limit.

7.5 *Ammonia and Chlorine*

Ambient air quality standards for SPM, NO_x and SO_x are available with CPCB. But for Cl_2 and NH_3, the ambient air quality standards are not available as yet. We tried hard to procure these from CPCB and US Environmental Protection Agency (USEPA) but were not successful. For this reason, we have not included these two variables in our computations of overall air quality discussed in the preceding section. The discussion in this section is indicative of how the air quality picture *may* look once we take these two variables also into account.

For the present, we have derived tentative standards for these chemicals on the basis of the logic that has gone in the setting up of standards for SO_x and NO_x. We found that ambient standards (AS) for SO_x and NO_x are related to their threshold lethal values (TLVs) by the empirical formulae:

AS1 = 0.025 * TLV (industrial area)
AS2 = 0.015 * TLV (residential area)
AS3 = 0.006 * TLV (sensitive area)

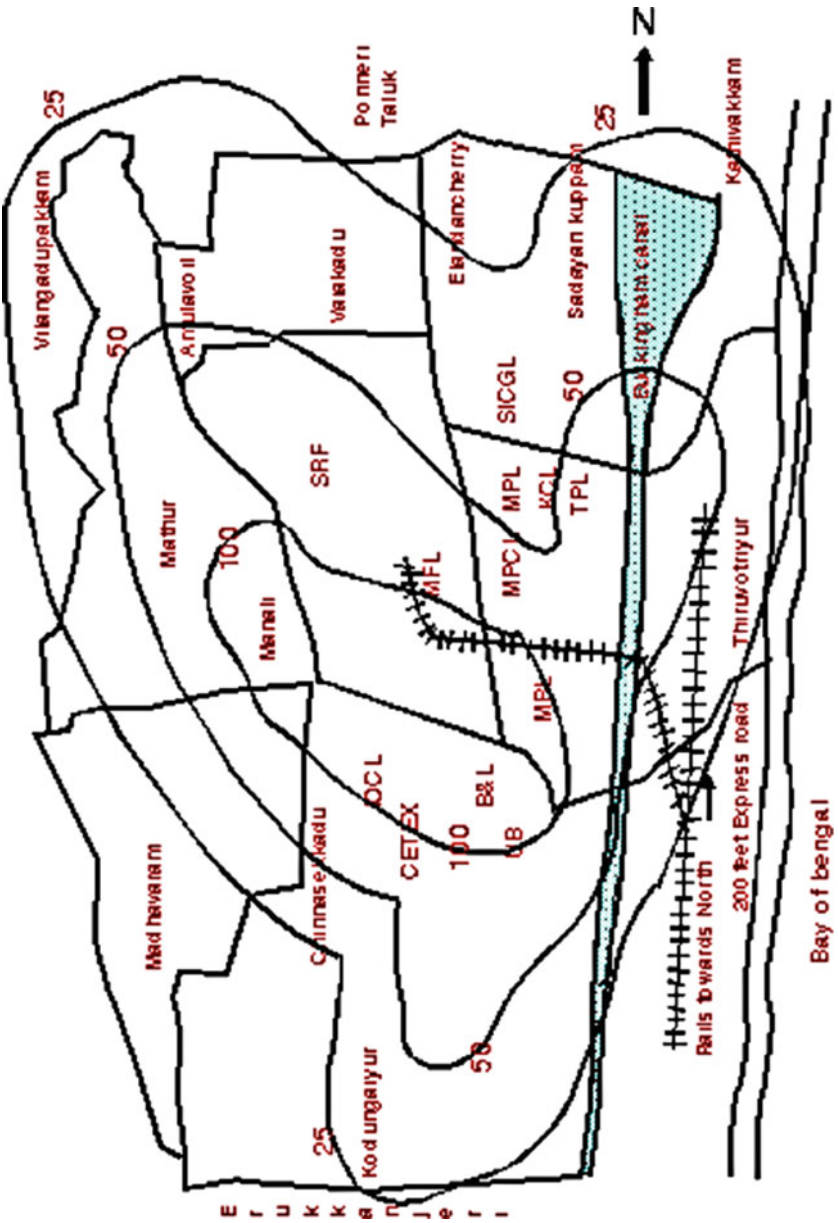

Fig. 9 Isopleths of SO_x ($\mu g/m^3$) during pre-monsoon

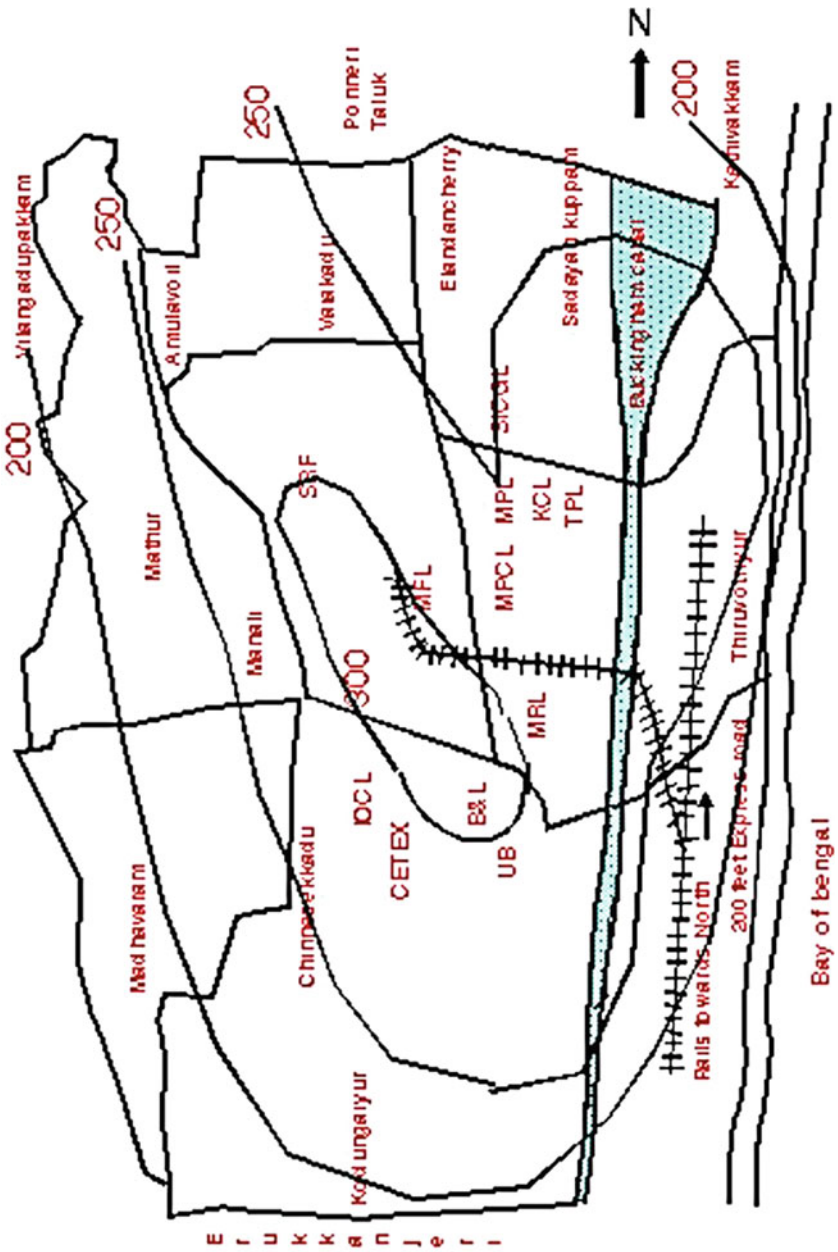

Fig. 10 Isopleths of SPM ($\mu g/m^3$) during pre-monsoon

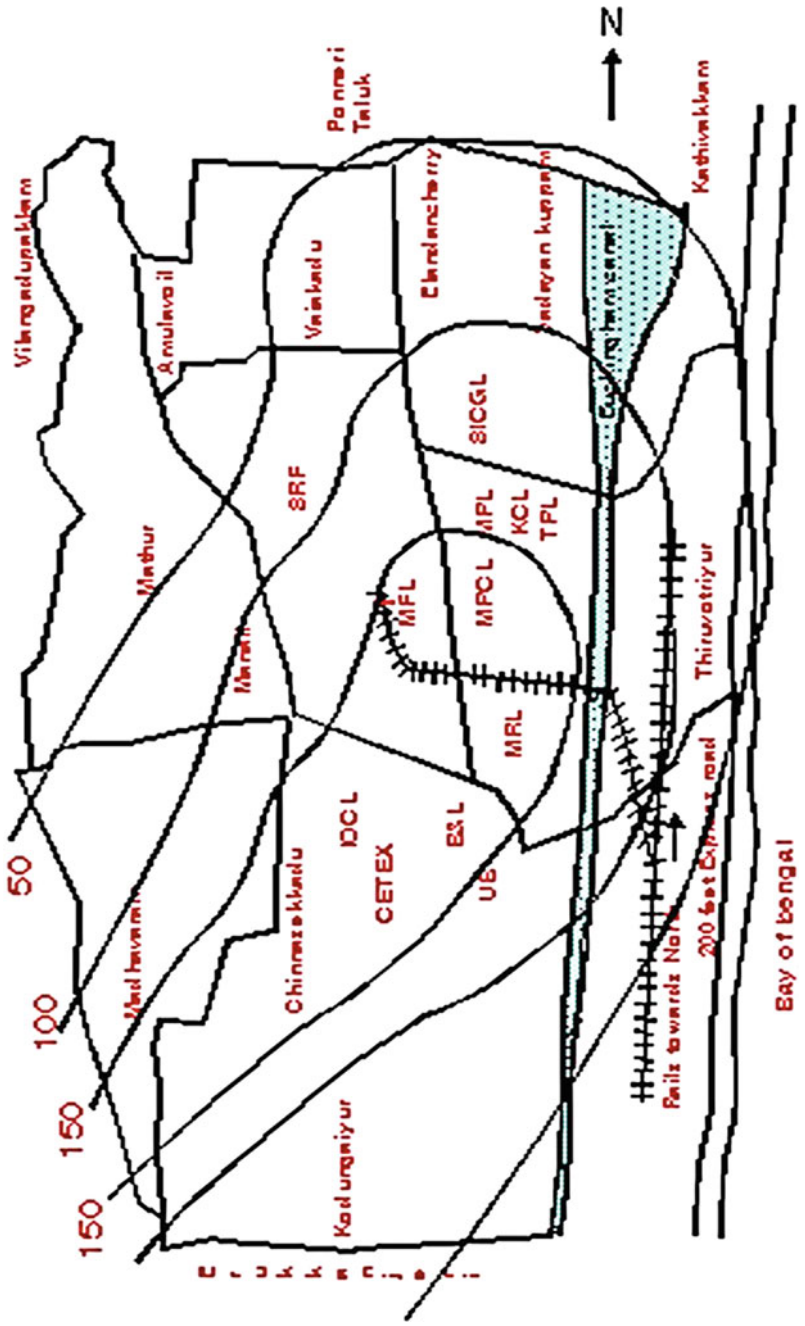

Fig. 11 Isopleths of SO_x ($\mu g/m^3$) during post-monsoon

Table 9 Tentative CPET standards for chlorine and ammonia

Area	Cl_2 (ppm)	NH_3 ($\mu g/m^3$)
Industrial and mixed use	0.025	375
Residential and rural area	0.015	225
Sensitive area	0.006	90

The ambient standards derived on the basis of these formulae for ammonia and chlorine are given in Table 9. We have termed them '*Tentative CPET (TCPET) standards*', where CPET represents Centre for Pollution Control and Energy Technology. For interpreting the results, we have used these TCPET standards.

7.5.1 Ammonia

The gist of the monitoring is as follows:

(a) In a large number of situations (Tables 10, 11, 12 and 13), more than 50% of samples had ammonia levels exceeding the TCPET limits.
(b) The most affected areas due to high NH3 concentration are Vaikkadu, Chinnasekkadu, Amulavoyal and Manali (Fig. 12). All-in-all the ambient air concentration of ammonia was significantly higher than the TCPET standards.

7.5.2 Chlorine

The monitoring reveals that:

(a) During monsoon, the concentration of Cl_2 exceeds up to 3 times the TCPET limits (Fig. 13).
(b) The areas under the impact of severe pollution load due to Cl_2 are the same as under NH_3 concentration (Tables 10, 11, 12 and 13).

7.6 Overall Seasonal Pattern

The following patterns emerge from the mass of data generated by us (Abbasi et al. 2013).

(1) In general, the concentrations of various pollutants are at their highest during post-monsoon and lowest during summer.
(2) The main pollutants at the residential and industrial area are NH_3, Cl_2, SO_x and SPM.

Table 10 Ambient air samples exceeding TCPET limits for chlorine and ammonia: pre-monsoon

S. No.	Season/months	Location	Samples during	% of samples exceeding TCPET limits					
				Cl_2			NH_3		
				I	R	S	I	R	S
1	Pre-monsoon June–August	Chinnasekkadu	Day	23	29	41	33	39	46
			Night	29	33	44	41	45	50
			Total	26	31	42	37	42	48
2		Periyasekkadu	Day	5	13	17	10	18	21
			Night	9	19	28	14	14	19
			Total	7	16	22.5	12	16	20
3		Manali School	Day	52	64	63	71	75	76
			Night	60	69	69	75	79	80
			Total	56	66.5	66	73	77	78
4		Manali Fire Station	Day	30	36	40	34	37	40
			Night	24	30	32	42	44	44
			Total	27	33	36	38	40	42
5		**TNHB**	Day	10	29	36	10	19	27
			Night	6	16	29	14	24	32
			Total	8	22	32.5	12	21.5	29.5
6		Chinnamathur	Day	4	13	39	13	16	34
			Night	6	17	38	19	21	39
			Total	5	15	38.5	16	18.5	36.5
7		Amulavoyal	Day	53	55	76	70	73	75
			Night	58	60	69	74	77	80
			Total	55.5	57.5	72.5	72	75	77.5
8		Madhavaram	Day	31	37	38	38	46	47
			Night	27	33	32	34	42	42
			Total	29	35	35	36	44	45
9		Vaikkadu	Day	59	60	63	70	73	75
			Night	63	64	67	74	77	79
			Total	61	62	65	72	75	77
10		Sadayankuppam	Day	60	65	69	73	74	76
			Night	53	60	65	70	70	71
			Total	56.5	62.5	67	71.5	72	73.5
11		Thiruvottriyur	Day	54	68	67	71	71	75
			Night	59	64	71	77	75	79
			Total	56.5	66	69	74	73	77

I Industrial zone
R Residential zone
S Sensitive zone

Table 11 Ambient air samples exceeding TCPET limits for chlorine and ammonia: monsoon

S. No.	Season/months	Location	Samples during	% of samples exceeding TCPET limits					
				Cl_2			NH_3		
				I	R	S	I	R	S
1	Post-monsoon December–February	Chinnasekkadu	Day	56	75	97	78	86	95
			Night	53	72	93	74	81	91
			Total	54.5	73.5	95	76	83.5	93
2		Periyasekkadu	Day	10	17	34	12	22	51
			Night	6	13	30	16	26	57
			Total	8	15	32	14	24	54
3		Manali School	Day	58	76	94	77	87	96
			Night	54	72	90	73	83	92
			Total	56	74	92	75	85	94
4		Manali Fire Station	Day	20	32	41	38	48	63
			Night	24	36	45	42	52	67
			Total	22	34	43	40	50	65
5		**TNHB**	Day	0	10	16	18	30	48
			Night	4	14	20	14	34	52
			Total	2	12	18	16	32	50
6		Chinnamathur	Day	20	40	60	30	46	64
			Night	23	36	64	34	50	60
			Total	21.5	38	62	32	48	62
7		Amulavoyal	Day	9	22	33	18	30	42
			Night	5	18	29	16	27	38
			Total	7	20	31	17	28.5	40
8		Madhavaram	Day	15	28	40	24	38	56
			Night	18	33	41	20	36	50
			Total	16.5	30.5	39.5	22	37	53
9		Vaikkadu	Day	57	73	89	73	81	94
			Night	60	76	94	75	87	98
			Total	58.5	74.5	91.5	74	84	96
10		Sadayankuppam	Day	52	72	98	75	90	97
			Night	58	76	94	71	87	93
			Total	55	74	96	73	88.5	95
11		Thiruvottriyur	Day	57	77	95	78	88	93
			Night	53	73	91	72	84	90
			Total	55	75	93	75	86	91.5

I Industrial zone
R Residential zone
S Sensitive zone

Table 12 Ambient air samples exceeding TCPET limits for chlorine and ammonia: post-monsoon

S. No.	Season/months	Location	Samples during	% of samples exceeding TCPET limits					
				Cl_2			NH_3		
				I	R	S	I	R	S
1	Monsoon September–November	Chinnasekkadu	Day	56	74	89	75	87	95
			Night	59	78	94	79	90	98
			Total	57.5	76	91.5	77	88.5	96.5
2		Periyasekkadu	Day	9	18	40	17	35	53
			Night	7	14	35	12	29	49
			Total	8	16	37.5	14.5	32	51
3		Manali School	Day	58	78	92	78	90	98
			Night	54	74	94	73	87	92
			Total	56	76	93	75.5	88.5	95
4		Manali Fire Station	Day	20	34	50	35	55	62
			Night	25	39	57	40	58	66
			Total	22.5	35.5	53.5	37.5	56.2	64
5		**TNHB**	Day	5	10	35	12	28	48
			Night	9	14	39	18	34	52
			Total	7	12	37	15	31	50
6		Chinnamathur	Day	22	40	61	30	48	59
			Night	26	44	64	35	52	61
			Total	24	42	62.5	32.5	50	60
7		Amulavoyal	Day	7	19	40	22	39	61
			Night	6	15	36	18	34	62
			Total	6.5	17	38	20	36.5	61.5
8		Madhavaram	Day	16	18	39	27	44	67
			Night	12	22	43	31	49	70
			Total	14	20	41	29	46.5	68.5
9		Vaikkadu	Day	58	74	89	78	87	95
			Night	55	78	93	74	82	99
			Total	56.5	76	91	76	84.5	97
10		Sadayankuppam	Day	53	75	89	74	86	92
			Night	58	79	93	78	89	97
			Total	55.5	77	91	76	87.5	94.5
11		Thiruvottriyur	Day	53	78	89	72	72	98
			Night	56	82	92	75	76	95
			Total	54.5	80	91.5	73	74	96.5

I Industrial zone
R Residential zone
S Sensitive zone

Table 13 Ambient air samples exceeding TCPET limits for chlorine and ammonia: summer

S. No.	Season/months	Location	Samples during	% of samples exceeding TCPET limits					
				Cl_2			NH_3		
				I	R	S	I	R	S
1	Summer March–May	Chinnasekkadu	Day	9	25	42	14	38	51
			Night	5	29	48	18	34	55
			Total	7	27	45	16	36	53
2		Periyasekkadu	Day	14	35	44	25	38	50
			Night	18	31	48	21	34	53
			Total	16	33	46	23	36	51.5
3		Manali School	Day	63	73	85	74	85	99
			Night	67	79	89	78	81	95
			Total	65	76	87	76	83	97
4		Manali Fire Station	Day	68	74	84	71	81	93
			Night	64	78	88	75	85	97
			Total	66	76	86	73	83	95
5		**TNHB**	Day	60	79	89	68	83	95
			Night	64	75	85	72	89	99
			Total	62	77	87	70	86	97
6		Chinnamathur	Day	62	75	94	73	83	95
			Night	66	79	90	76	87	99
			Total	64	77	92	74.5	85	97
7		Amulavoyal	Day	62	78	91	71	85	91
			Night	66	75	95	75	81	95
			Total	64	76.5	93	73	83	93
8		Madhavaram	Day	20	43	56	30	52	60
			Night	24	40	52	33	56	63
			Total	22	41.5	54	31.5	54	61.5
9		Vaikkadu	Day	62	73	92	78	89	95
			Night	66	76	96	74	85	92
			Total	64	74.5	94	76	87	93.5
10		Sadayankuppam	Day	61	78	96	74	87	98
			Night	58	74	92	70	83	94
			Total	59.5	76	94	72	85	96
11		Thiruvottriyur	Day	12	21	40	12	30	52
			Night	8	25	45	16	34	56
			Total	10	23	42.5	14	32	54

I Industrial zone
R Residential zone
S Sensitive zone

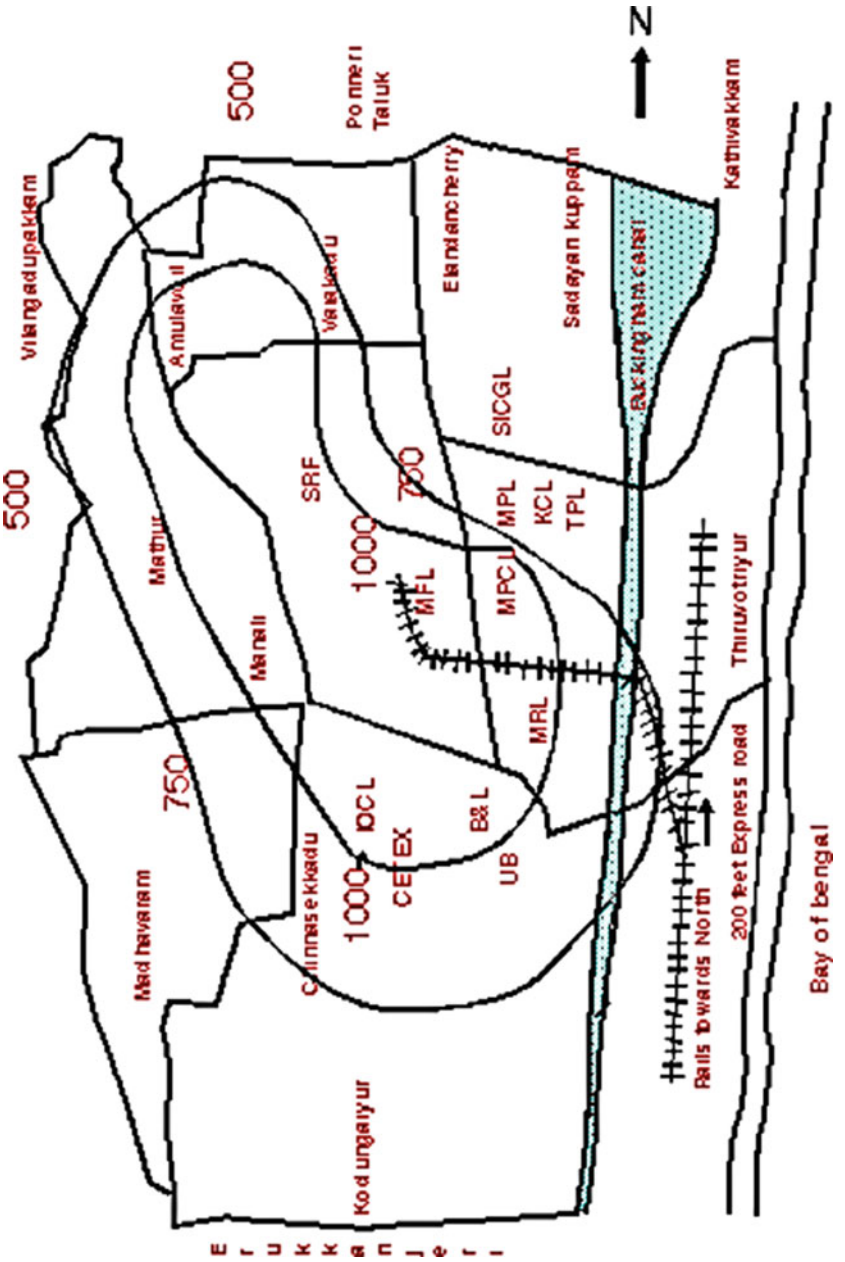

Fig. 12 Isopleths of NH_3 ($\mu g/m^3$) during monsoon

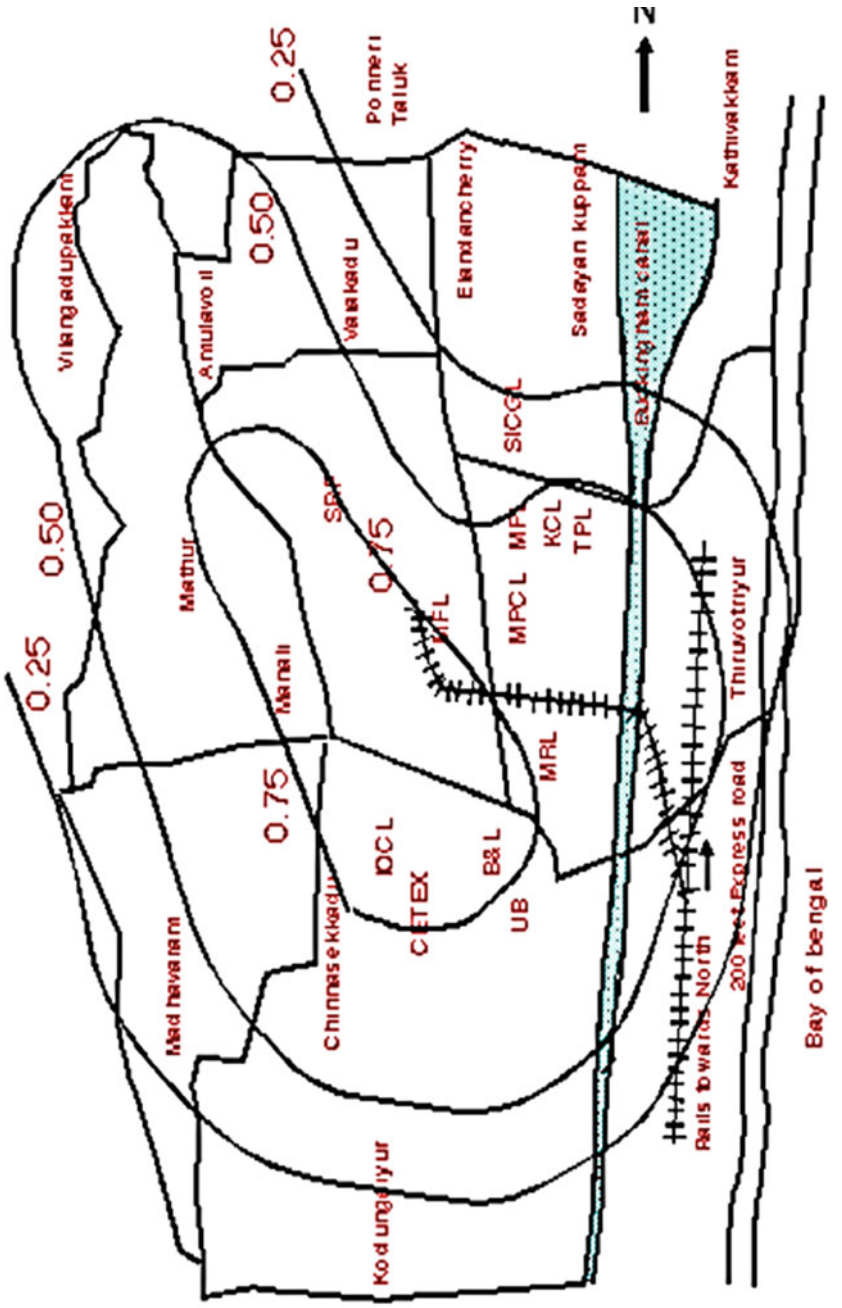

Fig. 13 Isopleths of Cl_2 (ppm) during monsoon

Plate 1 At times dense-gas plumes fall on the ground, posing serious health hazard

(3) During all four seasons (throughout the year), the air of MIC and the surrounding areas (14 km radius) is severely polluted when assessed on the basis of prevailing CPCB norms. It is not uncommon to final dense-gas plumes very close to the ground (Plate 1); one can be literally walking through or driving through such very unhealthy plumes.
(4) The hazardous industries in the region pose serious risk of air pollution, besides risk of major accidents (Abbasi and Abbasi 2011; Khan and Abbasi 1998, 1999).

8 Summary and Conclusion

Systematic studies based on proper reconnaissance, a representative sampling network, extensive sampling and meticulously done analysis reveal that the airshed of the study area—Manali Industrial Complex—is grossly polluted for most times in a year. The database created by the authors is expected to provide a frame of reference for future air quality assessments in the study area. It would, in turn, be helpful in monitoring the impacts of mitigative strategies.

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