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ORIGINAL ARTICLE

Development of baseline (air quality) data in Pakistan

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Abstract During 2003–2004, SUPARCO, the Pakistan Space and Upper Atmosphere Research Commission has conducted a year long baseline air quality study in country's major urban areas (Karachi, Lahore, Quetta, Rawalpindi, Islamabad and Peshawar). The objective of this study was to establish baseline levels and behavior of airborne pollutants in urban centers with temporal and spatial parameters. This study reveals that the highest concentrations of CO were observed at Quetta (14 ppm) while other pollutants like SO_2 (52.5 ppb), NO_x (60.75 ppb) and O_3 (50 ppb) were higher at Lahore compared to other urban centers like Karachi, Peshawar etc. The maximum particulate (TSP) and PM10 levels were observed at Lahore (996 ug/m^3 and 368 ug/m^3 respectively), Quetta (778 ug/m^3, 298 ug/m^3) and in Karachi (410 ug/m^3, 302 ug/m^3). In all major cities the highest levels were recorded at major intersections and variations were directly correlated with traffic density. These pollutants showed highest levels in summer and spring while lowest were observed in winter and monsoon. A data bank has been generated for future planning and air pollution impact studies.

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Introduction

Pakistan Space & Upper Atmosphere Research Commission (SUPARCO) has kept a very close watch on some atmospheric pollutants and trace metals for last many years. In its earlier study a chemical mass balance and multivariate analysis technique had been applied to delineate pollution sources in major cities of Pakistan. It was also reported that daily concentrations of particulate matter in Karachi city were found exceeding the ambient air quality standard during most of time of the year except in monsoons. A non-automotive source of Pb aerosols was also identified (Parekh *et al.*, 1987). Later (Ghauri *et al.*, 1994) demonstrated that most of the air pollution in major cities came from the combustion of fossil fuels in vehicles, power plants, cement and textiles mills, etc. Exposure to elevated pollutants concentrations or long continued exposure to low levels of ambient air pollutants has received increasing attention due to wide range of adverse effects of air pollutants on ecological system and human health (Dockery and Pope, 1994; Koenig, 2000; Pope *et al.*, 2002).

SUPARCO has undertaken air quality study during 2003–2004 in response to the initiative taken by FERTS (Fuel Efficiency in Road Transport Sector) of ENERCON/UNDP. This has generated the most needed information on environmental conditions of major cities of the country. One of the important objectives of the study was to establish the baseline (air quality) data in Pakistan with temporal and spatial parameters, to identify pollution sources and to determine their relative contribution towards prevailing ambient air quality of urban areas. The measurements of the following pollutants were carried out: SO_2, CO, CO_2, O_3, NOx, Hydrocarbons (Methane and Non-Methane), Particulates (TSP & PM10) and noise as well as meteorological parameters. TSP (total suspended particulates) are aerosol particles (sometimes even above 100 μm sizes) suspended in the air. PM10 means particulate mass of particles smaller than 10 μm in diameter. The study was carried out in six major cities of Pakistan i.e. Karachi, Lahore, Peshawar, Quetta, Rawalpindi and Islamabad and continued during the whole year. The state of air quality in urban areas of the country and various factors are being presented in the paper which are deteriorating air quality. A brief description for these cities is given below:

Karachi (Lat: 24°48′N, Long: 66°59′E) with a population of over 10 millions, is the biggest industrial and commercial center in Pakistan. It offers immense employment and business opportunities. It borders on the Arabian Sea, and is not under the influence of any other immediate industrial center. Therefore, we expect the pollutants present are entirely derived from local sources. With a population of more than seven million, Lahore (Lat: 31°35′N, Long: 74°20′E) is country's second largest city after Karachi. It occupies a choice site in the midst of fertile alluvial plains. It is country's second commercial and banking center. Although little industry is located in the city itself, Lahore serves as a distribution center for the heavily industrialized surrounding area. The city of Quetta (Lat: 30°12′N, Long: 67°E) is located in the mountainous region and lies at the mouth of the Bolan Pass. Here population is about 0.7 million. The district lies outside the range of the monsoon currents and the rainfall is scanty and irregular. Rawalpindi (Lat: 33°36′N, Long: 73°04′E) is an industrial and military center with a petroleum refinery, engineering workshops, steel-rolling mills, etc. Its population is over 1.4 million. Lying at altitudes ranging from 457 to 610 meters, Islamabad (Lat: 33°42′N, Long: 73°10′E) the capital city is an expanse of natural terraces drained by the Kurang River with the Margalla Hills in the north east. Population is 524,500 (National Census, 1998). Peshawar (Lat: 34°1′N, Long: 71°35′E) is situated near the entrance to the Khyber Pass. Local industries produce handicrafts and processed food. Population is 988,055 (National Census, 1998).

Methodology

Measurements of major pollutants were carried out using two Mobile Pollution Monitoring Labs. The fixed-point observations do not explain the whole situation because pollutants concentration may be dominated by local sources, making the results to some degree unrepresentative of the area as a whole. Air pollution in general, is much too complex and diverse because of the wide variability in the type, intensity, density and spatial distribution of emission sources. Interval of measurement was taken as 15 minutes and monitoring was carried out continuously for 48 h at a site and was repeated over the year for all the four seasons. One-hour mean were calculated from 15 min data. The peak value in hourly mean was quoted as maximum value. Any single extraordinary high peak was omitted (e.g. at some places a single CO peak was omitted and then 2nd highest value was quoted as maximum level). First time measurements at a site were marked as cycle 1, repeated measurements at the same site were marked as cycle 2, cycle 3 & cycle 4. There were total 33 sites in six cities and each site was monitored four times. Figure 1 shows the location of six cities on country map.

Measurement techniques

Suspended particulate matter was collected on 20 × 25 cm Whatman 41 filters using high-volume samplers. Air samples were collected for 24 h starting from 0800 h at a flow rate of 1.13 m^3/min. The flow was held at a constant volume by a mass flow controller and was corrected for local temperature and barometric pressure. A Sierra Andersen PM10 size-selective stage (Model 321-A) was used to eliminate coarse particles (>10 um). Weight of the filter paper was taken before and after the loading at constant humidity (maintained by keeping the filter paper in a desiccator for at least 24 h).

In accordance with 40 CFR part 53 of USEPA air quality assessment in term of NO_x, O_3, CO & SO_2 was carried out using the Mobile lab, which had on-board all analyzers. Ambient NO_x Monitor

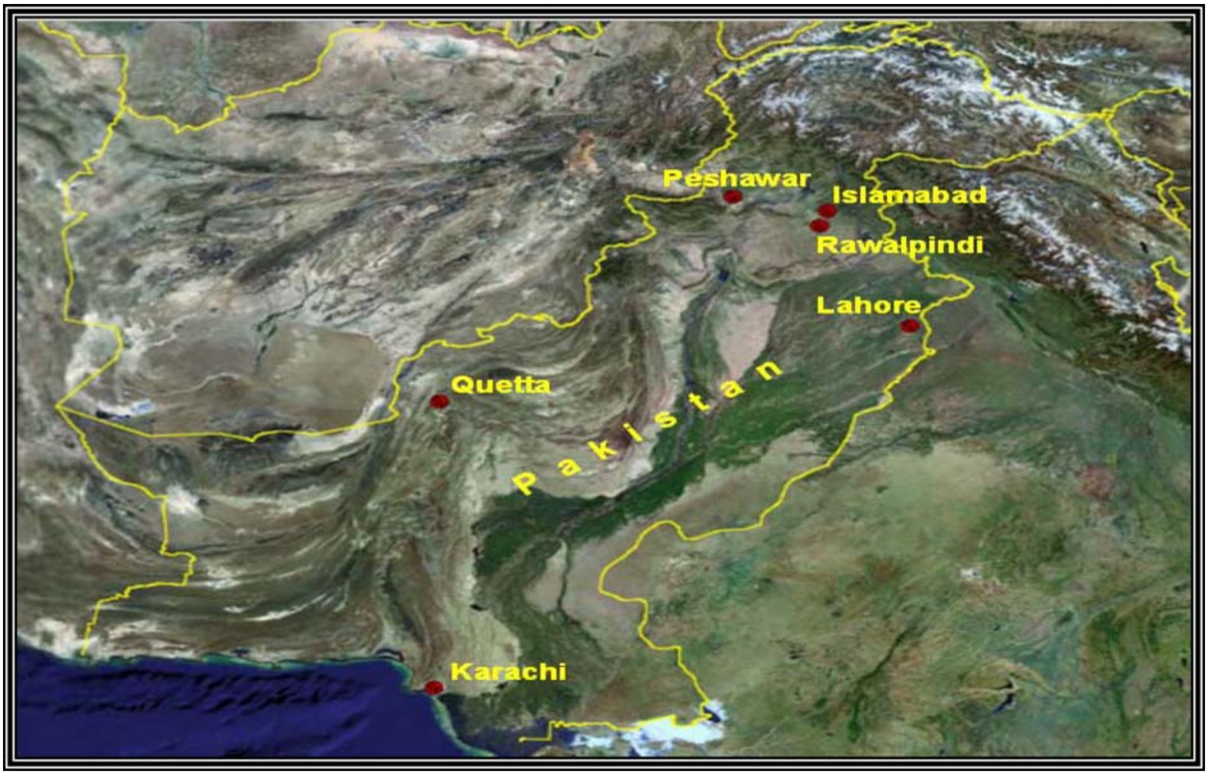

Fig. 1 Map of Pakistan showing locations of the cities

(Thermo Environmental Instrument Inc, USA, Model 42C) based on chemiluminescent technology was used to monitor NO_x levels. Ambient SO_2 was monitored using Environmental SA, France, Model AF 22M. The instrument is based on ultraviolet (UV) fluorescent measurement techniques. The instrument manufactured by M/S. Thermo Environmental Instruments Inc USA, (Model 48C and 48 H) were used for CO & CO_2 based on Gas Filter Correlation (GFC) technique. The Ozone Analyzer of Monitor Lab. Inc., USA (Model 8810) based upon UV photometry was employed for surface ozone measurements.

Results and discussion

The need to investigate ambient air quality appears paramount especially when bearing in mind that Pakistan is shifting its economic base from agriculture to industry. The environmental impacts of air pollutants include a number of effects on earth's atmosphere and on atmospheric processes. Generally, the sources of gaseous pollutants are considered in three categories, combustion sources, industrial manufacturing processes and natural emission mechanism. Industrial sources of particulates, like steel, cement factories, indiscriminate burning of solid wastes and heavy traffic loads are the largest sources of particulate matter besides noise and gaseous pollutants. Sulfur dioxide, carbon monoxide, hydrocarbons and nitrogen oxides are common emissions from auxiliary systems such as incinerators, steam boilers including processing residue waste fuel fire systems, glass and can manufacturing. The aerosol contents of the atmosphere are sensitive to the location of local sources and meteorological conditions. The growing air pollution is resulting in increased health cost, losses to crops and properties. The Economic Survey of Pakistan 2004 pinpoints vehicular and industrial emissions as the main causes of poor air quality (www.irinnews.org/report.asp). The Annual Economic Survey reports that the average compounded growth of vehicles in Pakistan is about 12 percent a year, and over the last two decades the total number of motor vehicles on the road has jumped from 0.8 million to almost 5 million (Lahore, 11 Oct 2004, IRIN, www.irinnews.org/report.asp). This recent

Table 1 Mean (48 h) & maximum (hourly) number of vehicles counted per day at monitoring sites (2003–2004)

City		Buses	Bick-up Jeeps	Loader Pick-ups	Tractors	Trucks	M/Cycles	Rickshaws (three wheelers)	Cars
Karachi (10 sites)	Mean	6512	2182	1928	18	1112	3400	1161	6330
	Maximum	16052	4335	6032	217	4259	7588	2586	10593
Quetta (3 sites)	Mean	3066	1222	1462	15	212	2228	1927	3376
	Maximum	5091	1733	2412	313	637	2740	2001	5153
Lahore (7 sites)	Mean	5256	1493	1559	30	515	3146	2213	4912
	Maximum	14928	3926	3818	277	1645	5496	3744	7921
Rawalpindi (3 sites)	Mean	4914	1276	1342	17	477	2865	1578	4268
	Maximum	10829	2409	4399	140	1163	4431	1972	6700
Islamabad (3 sites)	Mean	2764	1067	1054	13	220	1149	338	3008
	Maximum	5091	1711	2412	39	733	2001	1019	4679
Peshawar (5 sites)	Mean	3364	1226	920	42	327	1445	1035	3095
	Maximum	6531	3391	3259	229	840	3450	3125	4940

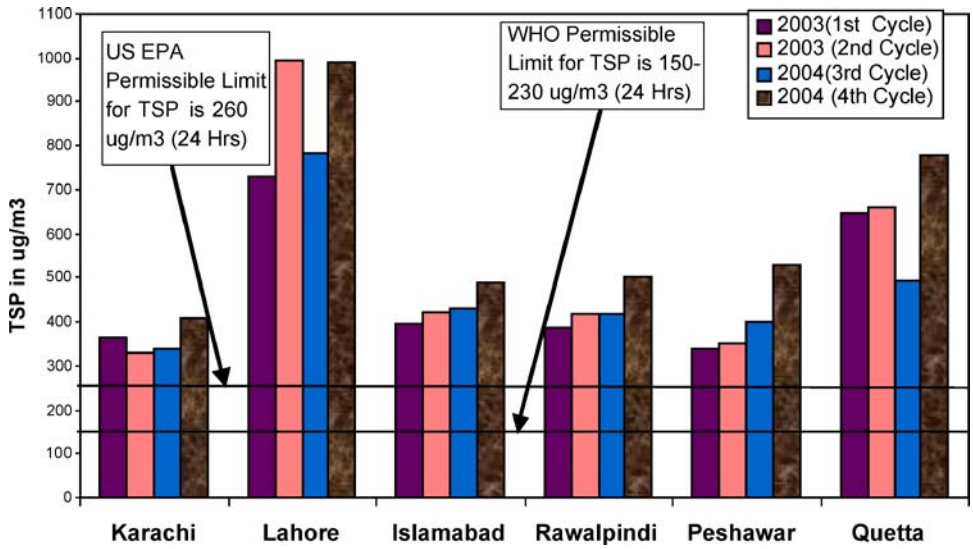

Fig. 2 Total suspended particles observed in six major cities of Pakistan

increase in the population of vehicles in urban areas not only leads to frequent traffic jams at intersections but also ultimately result in rise in pollutants levels as so far no vehicular pollution control device is employed in Pakistan. During this study, traffic density at each location was determined using digital photography. Table 1 gives daily mean and maximum number of vehicles counted at monitoring sites in various cities.

Particulate matter (TSP & PM10)

Airborne particulate matter is ubiquitous in the atmosphere and varies widely (spatially and temporally) in size, concentration and chemical composition. Particulate emissions to air are the main environmental challenges for industry and transport sectors. Also of concern are the sulfates and nitrate particles that are formed as a byproduct of SO_2 and NO_2 emissions, primarily from fossil fuel-burning in power plants and vehicular exhausts. According to the report of World Health Organization (WHO), South Asia has become one of the most polluted areas in the world due to its rapid industrialization and increasing population. Exposure to particulate matter leads to more visits to the doctor or emergency room. Health effects include coughing, wheezing, shortness of breath, aggravated asthma, lung damage (including decreased lung function and lifelong respiratory disease), and premature death in individuals with existing heart or lung diseases. In major urban areas of Pakistan, peoples of all ages suffer from throat infections especially when season is cold and dry. In Pakistan, like the other low-income countries the vehicular emissions have been dominated by emissions from old and poorly maintained vehicles that contribute to enhanced ambient concentrations of fine particulates & carbon monoxide. It has been observed that levels of most of air pollutants were higher in summer than in winter and monsoons, which can easily be interpreted in terms of time dependent changes primarily in meteorological conditions. In urban areas the higher concentrations of PM10 are indicative of higher traffic density, whereas higher TSP values are indicative of size reduction process such as iron, cement and ceramic industrial activities or natural dust entrainment. The particulate levels as monitored in different cities contain a significant amount of crustal dust, which is a peculiar characteristics of local soil (especially in north & eastern Pakistan), lack of vegetation and paved areas. It was observed that maximum TSP load was recorded during summer season and minimum in monsoon. Further daytime particulate load is higher than nighttime one, indicating more urban activities during day time. Lahore is facing alarming level of TSP followed by Quetta, Peshawar, Rawalpindi, Islamabad, and Karachi. The high TSP maximum (1 hr) TSP levels in these cities are 2 to 4 times higher than the standard limit of USEPA of 260 ug/m^3 (Fig. 2). Even the mean of 48 h exceeded the recommended limits (Tables 2–7)

The maximum (1 hr) TSP peaks were found at Chowk Yateem Khana, Lahore (996 ug/m^3), Satellite Town, Quetta (778 ug/m^3), Attock Oil Refinery, Rawalpindi (500 ug/m^3), Kohat Ada, Peshawar (530 ug/m^3) and I-9, Islamabad (490 ug/m^3), Civic-Center, Karachi (410 ug/m^3) as shown in Fig. 2. In Quetta trans-boundary dust storm (seasonal), fugitive emissions from lime stone quarries are major contributors. The dry weather, soil erosion, and lack of vegetation/trees, also contribute to higher level of TSP in addition to low dispersion in the valley. The dust and vehicular emissions are the major part in TSP load observed in five cities, whereas low TSP levels were observed in Karachi, which borders Arabian sea having different meteorological conditions of higher wind speed and humidity. There is a clear difference of TSP levels measured in monsoons (1st Cycle) and those

Table 2 The mean concentration (48 h) showing spatial and temporal variation of different gases, particles, lead and noise level at Islamabad

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise Level (dB)
Sector F-10	Cycle I /Monsoon 15 Aug to 16 Aug, 03	12.1	18.8	2.0	17.0	0.5	0.4	270.0	287	157	64.8	64.8
	Cycle II/Winter 3 Nov to 5 Nov, 03	16.7	21.2	2.8	20.0	0.7	0.6	303.2	301	159	71.7	72
	Cycle III/Spring 6 Mar to 8 Mar, 04	19.7	28	3.5	20.9	1.1	0.8	312.2	429	163	76.7	77
	Cycle IV/Summer 1 May to 3 May, 04	26.0	32	4.4	22	1.0	1.4	309.8	431	232	73.7	74
Poly Clininc	Cycle I/Monsoon 12 Aug to 14 Aug, 03	16	19.1	1.0	15	1.0	0.7	298	320	157	78.3	78
	Cycle II/Winter 31 Oct to 2 Nov, 03	18.9	23	1.7	18	1.2	1.2	308	350	159	72.5	73
	Cycle III/Spring 3 Mar to 5 Mar, 04	21.9	26	2.4	18	1.2	1.1	314.2	365	175	72.5	73
	Cycle IV/Summer 3 May to 5 May, 04	24	30	3.0	20	1.4	1.4	322.2	397	216	78.5	79
Sector I-9	Cycle I/Monsoon 10 Aug to 12 Aug, 03	16.9	20	2.4	11.8	0.9	0.7	306	373	173	66.9	66.9
	Cycle II/Winter 29 Aug to 31 Aug, 03	20	22.2	3.0	15	0.7	1.1	311.2	421	216	68.9	68.9
	Cycle III/Spring 1 Mar to 3 Mar, 04	22.2	22	3.7	16.8	1.1	0.9	319.5	427	224	73.8	73.8
	Cycle IV/Summer 1 May to 3 May, 04	28	26	4.0	18	1.6	1.2	325	433	238	76.7	77

Table 3 Mean of 48 hours showing spatial and temporal variations of different gases, particles, lead and noise level at Quetta

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise level (dB)
Mezan Chowk	Cycle I/Monsoon 26 jun to 27 jun, 03	30.4	36	6.37	28.5	0.9	0.8	395	642	277	5.2	72.8
	Cycle II/Winter 6 Nov to 8 Nov, 03	28	36	7.10	25	0.7	0.7	380	543	234	4.71	77
	Cycle III/Spring 18 Feb to 20 Feb, 04	20	19.8	7.39	15.3	0.5	0.8	289	467	183	3.81	76.2
	Cycle IV/Summer 13 May to 15 May, 04	38.38	45.3	8.23	34.4	0.75	1	358	563	272	5.8	77
Satellite Town	Cycle I/Monsoon 27 Jun to 29 Jun, 03	32	29	5.65	28	0.9	0.8	384	653	298	4.11	72.2
	Cycle II/Winter 31 Oct to 11 Nov, 03	25	32	5.8	26	0.7	0.7	381	553	285	3.44	76.1
	Cycle III/Spring 20 Feb to 22 Feb, 04	15.4	17.9	6.2	16.9	0.4	0.7	381	467	201	2.31	76.2
	Cycle IV/Summer 15 May to 17 May, 04	21.75	29.3	6.9	24.8	1	1	340	702	266.7	4.7	77.7
Gawal Mandi	Cycle I/Monsoon 29 Jun to 1 Jul, 03	32	38	7.10	29.8	0.9	0.8	385	710	286	4.24	70.8
	Cycle II/Winter 3 Nov to 5 Nov, 03	27.2	35.4	6.0	24.5	0.7	0.7	380	657	253	3.56	73
	Cycle III/Spring 23 Feb to 25 Feb, 04	16.9	27.3	6.7	9.6	0.5	0.6	353	416	201	2.54	60
	Cycle IV/Summer 18 May to 20 May, 04	26.8	31.3	7.3	26.9	1.4	1.2	366	553	252	4.28	61.9

measured in summer months (4th Cycle). The trend remained same for mean TSP levels, with maxima of means at Lahore and Quetta. Other cities, though exceeding prescribed limits of USEPA, had mean TSP levels around 350 ug/m^3 (Fig. 3).

The PM10 (particles measuring 10 microns or less) are particles likely to be inhaled by humans. These microscopic inhalable particles PM10 affect breathing and respiration and cause lung damage. Children, the elderly, and people suffering from heart or lung disease are especially at risk. Higher levels of particulates especially PM10 are attributed to large number of 2 stroke vehicles, diesel driven vehicles and adulteration of petrol/diesel. The maximum (I hr) PM10 levels were again observed at Lahore (368 ug/m^3), Quetta (331 ug/m^3), Rawalpindi (276 ug/m^3), Peshawar (350 ug/m^3) and Islamabad (280 ug/m^3), Karachi (302 ug/0m^3) (Fig. 4). These levels were clearly higher in summer months (4th cycle) as compared to other seasons (Tables 2–7). At most of the sites, the mean (48 h) PM10 level exceeded the USEPA standard limit of 150 ug/m^3 (Fig. 5). However comparatively lowest PM10 concentrations has been recorded at Baloch Colony, Karachi (99 ug/m^3) and F-10, Islamabad (126 ug/m^3), which is a clear indication that these sites have lesser activities and were visited by comparatively fewer vehicles.

Gaseous pollutants

The ever increasing vehicular emissions are the main factor leading to bad air quality in urban areas. Motor vehicles account for about 90 percent of total emissions of hydrocarbons, NO_x, particles and CO. Oxides of nitrogen produced under high temperature combustion are major criteria pollutants that are precursors to photochemical smog, ozone and acid formation. Oxides of nitrogen are found within limit but their concentrations in the ambient air has been found increasing since the compressed natural gas (CNG) was introduced in vehicles without any catalytic converters.

In all the six cities, NO_x levels fall within specified U.S. ambient air quality standards (50 ppb as annual mean, 100–170 ppb as one hourly mean). Lahore city has shown highest levels of nitrogen oxides, which was caused by the heavy traffic around the sampling sites, however stationary sources such as power plants around the city are also the contributers. The overall NO_x concentrations ranged 5.4–60.7 ppb during 24 h at

Table 4 The mean concentration (48 h) showing spatial and temporal variation of different gases, particles, lead and noise level at Lahore

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise level (dB)
Chowk Yateem Khana	Cycle I/Monsoon 9 Jul to 11 Jul, 03	21.4	25.6	4.2	16.8	1.0	0.8	337.6	510	263	5.01	85.5
	Cycle II/Winter 23 Sep to 25 Sep, 03	25.6	30.8	5.4	17.9	0.8	0.9	379.1	690	269	4.78	82.4
	Cycle III/Spring 24 Mar to 26 Mar, 04	30.6	36.3	4.8	22.9	1.3	1.6	384	785	280	4.68	85.8
	Cycle IV/Summer 7 Jun to 9 Jun, 04	31	53.7	7.4	30.5	1.6	1.9	380	851	293	4.8	78.0
Azadi Chowk	Cycle I/Monsoon 12 Jul to 14 Jul, 03	23.4	30.9	3.8	20.8	1.2	1.2	350.8	460	201	5.12	85.6
	Cycle II/Winter 25 Sep to 27 Sep, 03	22.9	27.1	4.6	20.6	1.3	1.2	356.1	561	231	4.56	76.9
	Cycle III/Spring 26 Mar to 28 Mar, 04	27.3	32	4.5	25.7	1.3	1.5	362.1	580	268	4.02	79
	Cycle IV/Summer 9 Jun to 11 Jun, 04	29.8	48	6.7	29.1	1.6	1.4	379.6	769	273	4.5	73.4
Shalimar	Cycle I/Monsoon 28 Jul to 30 Jul, 03	17.7	24.5	2.8	19.8	0.8	1.2	326.2	308	168	3.45	75.1
	Cycle II/Winter 23 Sep to 25 Sep, 03	20.7	24.7	3.45	19.9	0.7	1.0	330.2	360	205	2.98	82.9
	Cycle III/Spring 29 Mar to 31 Mar, 04	24.3	30.9	3.8	26.5	1.0	1.1	337.3	372	255	2.81	87.0
	Cycle IV/Summer 12 Jun to149 Jun, 04	25.7	31.2	4.9	26.7	1.3	1.7	344.4	418	288	3.2	86.9
Qurtaba Chowk	Cycle I/Monsoon 14 Jul to 17 Jul, 03	16	28.3	2.2	18.7	0.7	1.1	333.6	327	119	2.98	71.7
	Cycle II/Winter 30 Sep to 1 Oct, 03	14.7	22.8	3.3	22.1	1.1	1.3	339.9	327	119	2.98	80.3
	Cycle III/Spring 31 Mar to 2 Apr, 04	24.1	30.1	3.0	22.1	1.0	1.5	347.6	331	125	3.01	84.7
	Cycle IV/Summer 14 Jun to 16 Jun, 04	26.9	35	3.9	26.0	1.2	1.5	354.5	818	260	3.5	78.7
Bank Square	Cycle I/Monsoon 17 Jul to 19 Jul, 03	16.9	23.0	2.0	13.7	0.7	1.1	324.1	220	130	2.76	70.5
	Cycle II/Winter 3 Oct to 5 Oct, 03	19.1	24.6	3.9	21.1	1.0	1.3	334.9	211	148	2.45	76.6
	Cycle III/Spring 3 Apr to 5 Apr, 04	19.9	26.7	2.5	23.6	1.0	1.3	341.5	269	149	2.46	81.2
	Cycle IV/Summer 17 Jun to 19 Jun, 04	23.1	30.2	2.8	27.3	1.3	1.6	353.9	746	265	2.9	81.1
Ichra	Cycle I/Monsoon 6 Jul to 7 Jul, 03	18.4	24.0	3.9	16.2	0.8	1.3	341.5	400	95	4.14	73.8
	Cycle II/Winter 3 Oct to 5 Oct, 03	19.1	24.6	3.8	21.1	1.0	1.3	344.9	608	164	3.89	77.3
	Cycle III/Spring 5 Apr to 7 Apr, 04	21.6	28.8	4.3	27.3	1.4	1.7	364	750	200	3.91	80.4
	Cycle IV/Summer 197 Jun to 21 Jun, 04	24.9	50	4.5	30.2	1.3	1.7	340	808	265	4.4	80.4
Lhr Airport	Cycle I/Monsoon 22 Jul to 24 Jul, 03	15.9	23.6	1.8	16.2	0.8	1.4	326.1	193	105	2.37	63.1
	Cycle II/Winter 8 Oct to 10 Oct, 03	17.9	19.8	2.0	17.7	0.9	1.3	332.2	150	112	2.01	64.3
	Cycle III/Spring 8 Apr to 10 Apr, 04	21.3	23.5	2.0	22.9	1.0	1.6	340	161	117	2.05	80.3
	Cycle IV/Summer 22 Jun to 24 Jun, 04	26	38	2.9	24.8	1.3	1.7	338	518	224	2.6	82

Table 5 The mean concentration (48 h) showing spatial and temporal variation of different gases, particles, lead and noise level at Karachi

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise level (dB)
Civic Center	Cycle I/Monsoon 7 Sep to 9 Sep, 03	18.6	33.1	5.0	30.8	1.1	1.6	328.9	358	220	5.03	73.3
	Cycle II/Winter 5 Nov to 7 Nov, 03	20.1	24.5	7.0	18.5	1.4	0.8	326.9	332	146	4.79	83.7
	Cycle III/Spring 5 Mar to 7 Mar, 04	23.8	28.8	7.8	23.1	2.0	1.2	341.9	339	231	4.8	87.7
	Cycle IV/Summer 23 May to 25 May, 04	24.2	29.9	8.0	28.6	2.1	1.6	345.8	410	302	5.8	84.7
Garden	Cycle I/Monsoon 10 Sep to 12 Sep, 03	17.1	26.5	4.0	28.3	2.0	0.9	316.5	341	220	4.83	76.3
	Cycle II/Winter 7 Nov to 9 Nov, 03	25.4	22.5	5.5	16.0	1.3	1.0	332.2	245	164	3.67	84.1
	Cycle III/Spring 7 Mar to 9 Mar, 04	29	27	6.0	12	1.5	1.1	339	321	189	4.31	91
	Cycle IV/Summer 25 May to 27 May, 04	27.0	33.2	7.0	26.5	1.5	1.3	360.0	331	203	4.3	87.5
I.I. Chung. Rd	Cycle I/Monsoon 13 Sep to 15 Sep, 03	17.9	20.0	3.9	27.0	0.6	0.9	327.2	333	198	3.9	78.8
	Cycle II/Winter 10 Nov to 12 Nov, 03	19.2	23.6	5.7	24.6	0.8	1.2	333.0	289	201	3.2	82.5
	Cycle III/Spring 10 Mar to 12 Mar, 04	25	28	6.2	27	1.1	1.6	344	288	210	3.1	89
	Cycle IV/Summer 28 May to 30 May, 04	26.7	27.6	7.6	30.3	1.0	2.0	354.5	300	222	3.5	86.2
Korangi	Cycle I/Monsoon 16 Sep to 18 Sep, 03	16.5	22.3	4.6	24.4	0.9	0.9	339.9	367	239	3.81	82.7
	Cycle II/Winter 14 Nov to 16 Nov, 03	20.3	22.2	6.5	18.2	0.8	1.2	341.0	329	208	3.25	82.5
	Cycle III/Spring 13 Mar to 15 Mar, 04	26	27	7.0	22	1.1	1.4	349	337	217	3.2	87
	Cycle IV/Summer 30 May to 1 Jun, 04	27.5	33.0	8.0	24.5	1.4	1.6	348.9	346	228	3.2	85.5
Gizri	Cycle I/Monsoon 17 Nov to 19 Nov, 03	18.1	20.6	2.6	25.3	0.4	0.7	324.2	275	219	3.35	84.9
	Cycle II/Winter 19 Nov to 21 Nov, 03	21.8	23.4	3.2	20.3	0.7	1.0	333.0	258	199	3.03	82.4
	Cycle III/Spring 16 Mar to 18 Mar, 04	27	29	4.0	24	0.8	1.3	345	262	204	3.1	85
	Cycle IV/Summer 2 Jun to 4 Jun, 04	27.8	32.1	6.0	22.4	0.9	2.0	349.5	287	216	3.5	84.5
Site	Cycle I/Monsoon 22 Sep to 24 Sep, 03	18.1	21.5	4.0	26.7	0.5	1.0	330.8	360	215	5.87	83.1
	Cycle II/Winter 22 Nov to 24 Nov, 03	22.6	25.4	4.5	27.6	1.4	1.0	336.0	287	198	4.36	76.8
	Cycle III/Spring 18 Mar to 20 Mar, 04	27	29	5.0	31	1.2	1.7	344	282	189	4.23	83
	Cycle IV/Summer 4 Jun to 6 Jun, 04	27.0	32.6	7.4	28.1	1.5	2.0	350.1	296	201	4.4	81.5
Nazimabad	Cycle I/Monsoon 25 Sep to 27 Sep, 03	12.6	23.3	4.3	25.0	0.8	0.9	334.1	285	185	3.25	78.6
	Cycle II/Winter 25 Nov to 27 Nov, 03	17.4	18.5	4.4	18.4	1.0	1.0	338.8	254	151	3.03	75.9
	Cycle III/Spring 21 Mar to 23 Mar, 04	24	24	5.2	22	0.9	1.6	354	208	163	3.12	86
	Cycle IV/Summer 7 Jun to 9 Jun, 04	23.0	29.6	7.3	21.1	1.0	1.2	357.1	280	184	3.7	85.4
F.B.Area	Cycle I/Monsoon 28 Sep to 30 Sep, 03	15.8	25.5	4.4	25.2	0.7	1.1	338.2	268	172	4.21	81.4
	Cycle II/Winter 6 Nov to 8 Nov, 03	16.8	25.9	4.6	25.8	0.8	0.7	325.7	286	188	3.67	78.8
	Cycle III/Spring 24 Mar to 26 Mar, 04	22.8	30.9	4.8	28.8	0.7	1.1	333.7	268	172	3.7	83.8
	Cycle IV/Summer 9 Jun to 11 Jun, 04	18.3	35.9	6.2	26.6	1.0	1.2	345.8	286	188	3.7	80.6
Balooch	Cycle I/Monsoon 1 Oct to 3 Oct, 03	15.9	20.9	3.0	26.2	0.7	0.8	322.5	289	160	4.13	82.2
	Cycle II/Winter 28 Nov to 30 Nov, 03	20.7	22.4	3.4	22.8	0.8	0.7	325.7	245	146	3.97	78.8
	Cycle III/Spring 27 Mar to 29 Mar, 04	25.7	28.4	4.2	25.8	0.6	1.1	337.7	255	139	3.9	80
	Cycle IV/Summer 12 Jun to 14 Jun, 04	30.7	37.2	5.8	26.2	0.6	1.0	351.4	279	156	3.2	82.4
Jauhar	Cycle I/Monsoon 4 Oct to 6 Oct, 03	19.8	21.7	3.5	24.1	0.6	0.7	324.7	228	128	4.98	83.8
	Cycle II/Winter 30 Nov to 2 Nov, 03	17.7	22.1	3.2	23.8	1.0	0.9	327.3	210	178	4.45	80.4
	Cycle III/Spring 29 Mar to 31 Mar, 04	22.6	26.6	4.0	27.8	1.2	0.8	340.3	220	186	4.16	87.4
	Cycle IV/Summer 14 Jun to 16 Jun, 04	24.9	27.3	5.6	25.5	1.2	1.4	343.9	247	202	4.46	82.2

Table 6 The mean concentration (48 h) showing spatial and temporal variation of different gases, particles, lead and noise level at Rawalpindi

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise level (dB)
Faizabad	Cycle I/Monsoon 28 Jul to 30 Jul, 03	14.0	16	3.0	12.7	0.5	0.9	305.7	244	131	2.2	74.8
	Cycle II/Winter 15 Oct to 17 Oct, 03	15	19	3.6	18	0.6	0.9	309	282	168	2.1	74.9
	Cycle III/Spring 17 Feb to 19 Feb, 04	16.1	20	5.0	22.2	0.6	0.9	314.3	308	179	1.75	75.9
	Cycle IV/Summer 9 May to 11 May, 04	16.8	23	5.5	26.8	1.0	1.0	323.2	392	215	2.6	79.9
Raja	Cycle I/Monsoon 30 Jul to 1 Aug, 03	13.4	22	3.2	13.8	0.6	1.0	295.2	273	179	3.46	70.2
	Cycle II/Winter 17 Oct to 19 Oct, 03	15.8	23	4.2	16.3	0.7	1.1	308	313	168	3.02	72
	Cycle III/Spring 19 Feb to 21 Feb, 04	16.8	23	4.8	20.3	0.8	1.1	308	327	131	2.9	76.8
	Cycle IV/Summer 11 May to 13 May, 04	18.1	26	5	21	1.0	1.2	312	416	215	3.8	81.8
Radio	Cycle I/Monsoon 2 Aug to 4 Aug, 03	15	21	1.8	12	0.5	1.2	311	273	131	3.5	71.9
	Cycle II/Winter 20 Oct to 22 Oct, 03	15.8	22.0	2.0	15	0.6	1.3	315	290	158	3.7	73.9
	Cycle III/Spring 22 Feb to 24 Feb, 04	19.0	23	2.5	19	0.8	1.5	322	300	160	4.0	77.8
	Cycle IV/Summer 14 May to 16 May, 04	19.0	27	3.8	20.1	0.8	1.6	356	459	236	4.7	77.7
Attock	Cycle I/Monsoon 4 Aug to 6 Aug 03	12.9	18	3.0	13	0.4	0.6	302	389	167	3.75	69.6
	Cycle II/Winter 22 Oct to 24 Oct, 03	13.9	20.0	3.8	14	0.7	0.8	308	416	200	3.65	66.0
	Cycle III/Spring 24 Feb to 26 Feb, 04	15	21	4.2	15.2	0.8	1.2	314	420	208	3.37	66.4
	Cycle IV/Summer 16 May to 18 May, 04	14.8	22.1	4.5	17	1.2	1.3	315	453	245	4.3	66.5
Nasirabad	Cycle I/Monsoon 7 Aug to 9 Aug, 03	13.3	17	2.0	12	0.4	0.9	299	317	173	3.1	67.9
	Cycle II/Winter 25 Oct to 27 Oct, 03	14.8	18	2.4	14.0	0.6	1.1	308	357	188	3.5	72.5
	Cycle III/Spring 27 Feb to 29 Feb, 04	17.3	22	3.2	15.0	0.8	1.1	312	358	190	3.37	69.5
	Cycle IV/Summer 19 May to 21 May, 04	19	25	4.5	19.9	0.8	1.2	314	464	248	4.3	69.5

Table 7 The mean concentration (48 h) showing spatial and temporal variation of different gases, particles, lead and noise level at Peshawar

Site	Cycle/season	SO_2 (ppb)	NO_x (ppb)	CO (ppm)	O_3 (ppb)	HC Methane (ppm)	Non-methane (ppm)	CO_2 (ppm)	TSP (SPM) ug/m^3	PM10 ug/m^3	Lead ug/m^3	Noise level (dB)
General Bus Stand	Cycle I/Monsoon 21 Aug to 23 Aug, 03	18	21	2.4	20	0.4	0.8	356	302	213	3.23	72
	Cycle II/Winter 10 Nov to 12 Nov, 03	19	27	3.2	20	0.8	1.6	358	312	219	3.9	72
	Cycle III/Spring 10 Mar to 12 Mar, 04	23	27	3.6	23	2.1	2.0	372	350	291	4.5	74
	Cycle IV/Summer 23 May to 25 May, 04	29	35	3.8	24	2.4	2.2	379	385	317	4.8	81
Saddar	Cycle I/Monsoon 23 Aug to 25 Aug, 03	14	20	2.1	21	0.6	0.8	312	341	170	3.92	70
	Cycle II/Winter 12 Nov to 14 Nov, 03	19	21	2.5	24	0.7	1.2	322	358	173	3.2	70
	Cycle III/Spring 15 Mar to 17 Mar, 04	19	23	3.1	27	1.0	1.4	328	416	198	4.3	73
	Cycle IV/Summer 25 May to 27 May, 04	24	28	3.5	29	0.8	1.7	340	421	208	4.72	79
Kohat Ada	Cycle I/Monsoon 30 Aug to 1 Sep, 03	24	24	2.8	18.8	0.9	1.1	321	400	204	3.5	74.4
	Cycle II/Winter 15 Nov to 17 Nov, 03	25.2	27	3.0	20	1.0	1.3	337	448	239	4.2	69.2
	Cycle III/Spring 20 Mar to 22 Mar, 04	26.2	29	3.3	22	1.1	1.4	360	451	295	4.5	70.3
	Cycle IV/Summer 28 May to 30 May, 04	29	30	4.0	21.7	1.6	1.6	373	474	305	5.3	77
Dabgri	Cycle I/Monsoon 1 Sep to 3 Sep, 03	19.2	21.3	2	20.9	0.5	0.8	313	240	214	3.6	77
	Cycle II/Winter 17 Nov to 19 Nov, 03	20.0	26	2.5	23.1	0.8	1.1	328	241	224	4.7	65.2
	Cycle III/Spring 17 Mar to 19 Mar, 04	21	27	3.1	27.7	1.0	1.6	341	310	230	4.4	71.7
	Cycle IV/Summer 30 May to 1 Jun, 04	22	30.2	3.3	30.9	1.3	1.7	356	414	240	4.8	77.7
Hyatabad	Cycle I/Monsoon 27 Aug to 29 Aug, 03	15	20	1.8	21.1	0.3	0.6	313	261	142	2.02	67.5
	Cycle II/Winter 20 Nov to 22 Nov, 03	19.2	23	2.0	22	0.6	1.3	328	301	153	2.8	64.6
	Cycle III/Spring 12 Mar to 14 Mar, 04	23	29.4	3.8	25	1.1	1.5	373	305	156	2.89	72
	Cycle IV/Summer 2 Jun to 4 Jun, 04	28	32.9	4.3	25.1	1.3	1.7	382	432	179	3.02	78

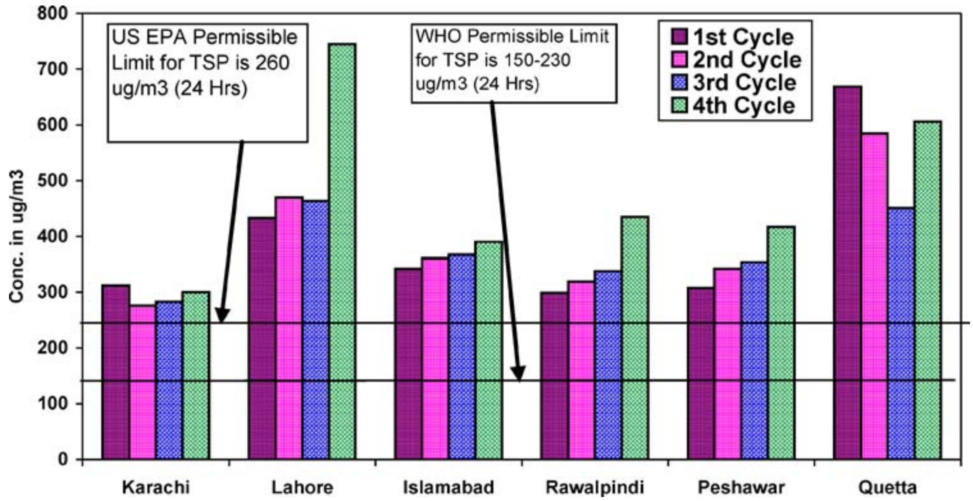

Fig. 3 Mean concentration (48 h) of TSP in six major cities of Pakistan

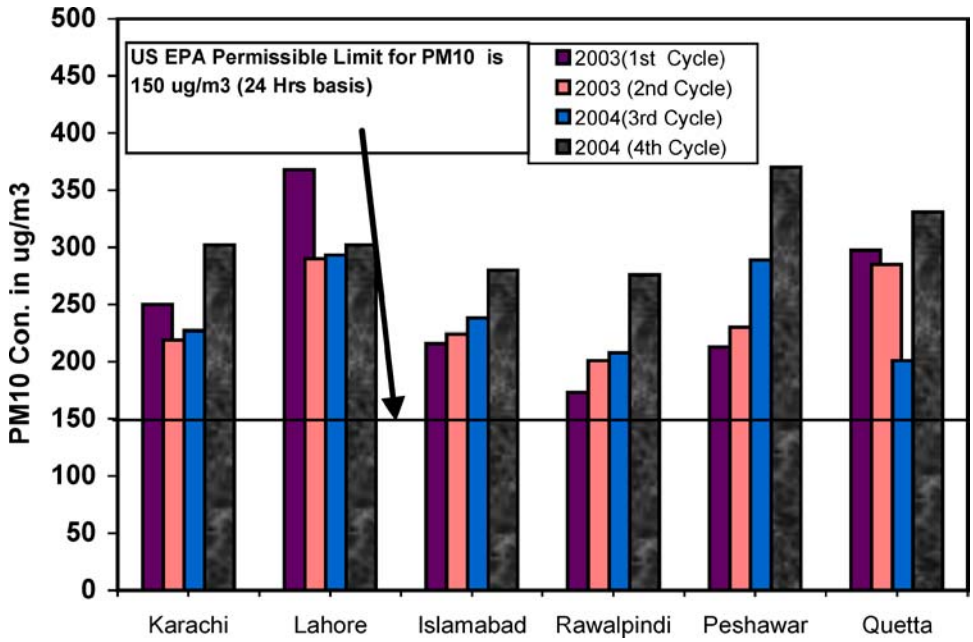

Fig. 4 Max. concentration of PM10 in six major cities of Pakistan

all 33 sampling sites. Consequent upon the conversion of gasoline driven engines to CNG and LPG (Liquid Petroleum Gas) usage, NO_x emissions has increased and presently it is second to CO as the most prevalent pollutant.

SO_2 is the principal pollutant supposed to be causing acid deposition after being oxidized to sulfuric acid. Coal burning is the single largest source of atmospheric SO_2, accounting for about 50% of annual global emissions in recent years. Man-made sulphur emission in the form of SO_2 arises mostly from combustion of fuel containing trace amounts of inorganic and organic sulphur. The maximum daily SO_2 concentration recorded in Lahore was 53 ppb and at Quetta around 46 ppb compared to other cities. However ambient mean SO_2 levels in urban areas are within USEPA permissible limit of 140 parts per billion (Fig. 7).

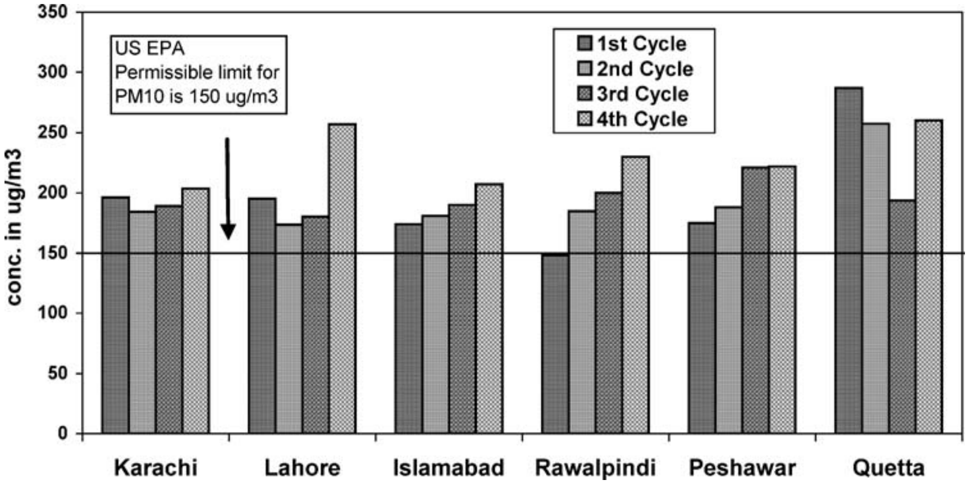

Fig. 5 Mean conc. of PM10 in six major cities of Pakistan

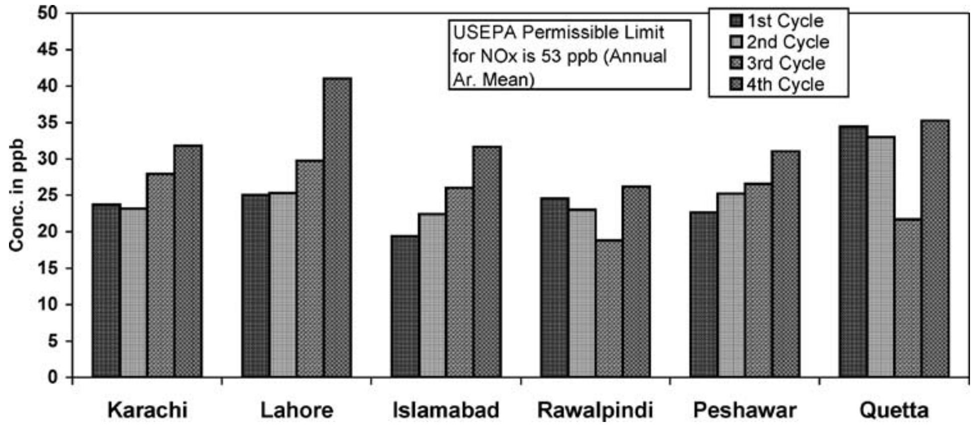

Fig. 6 Mean conc. of NO_x in six major cities of Pakistan

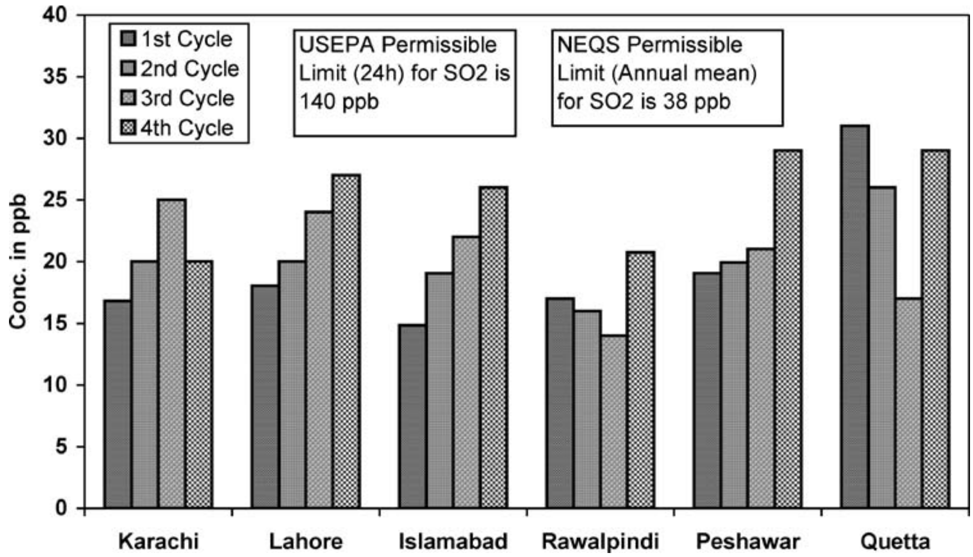

Fig. 7 Mean (48 h) conc. of SO_2 in six cities of Pakistan

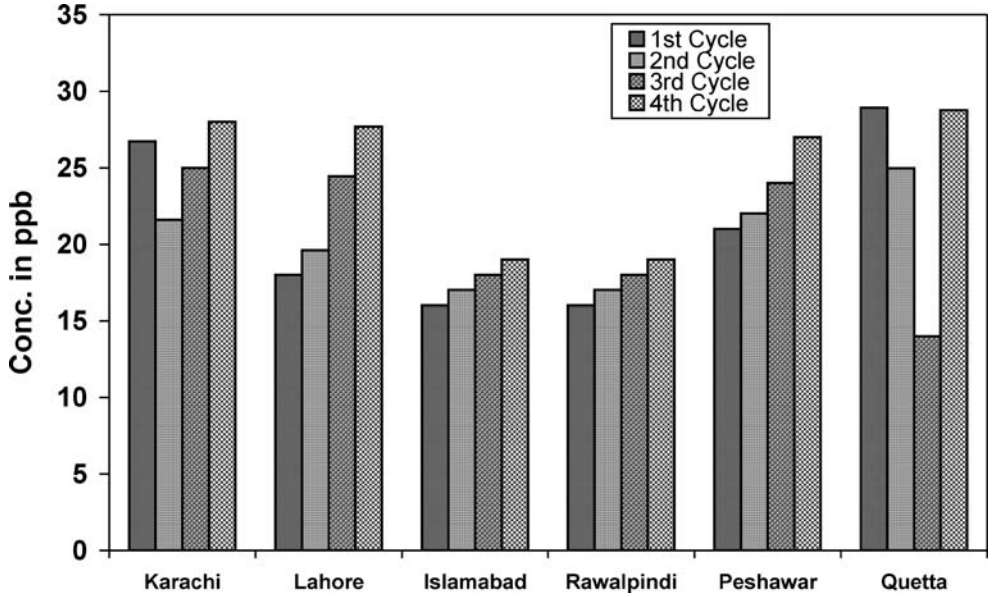

Fig. 8 Mean average concentration of ozone in six major cities of Pakistan

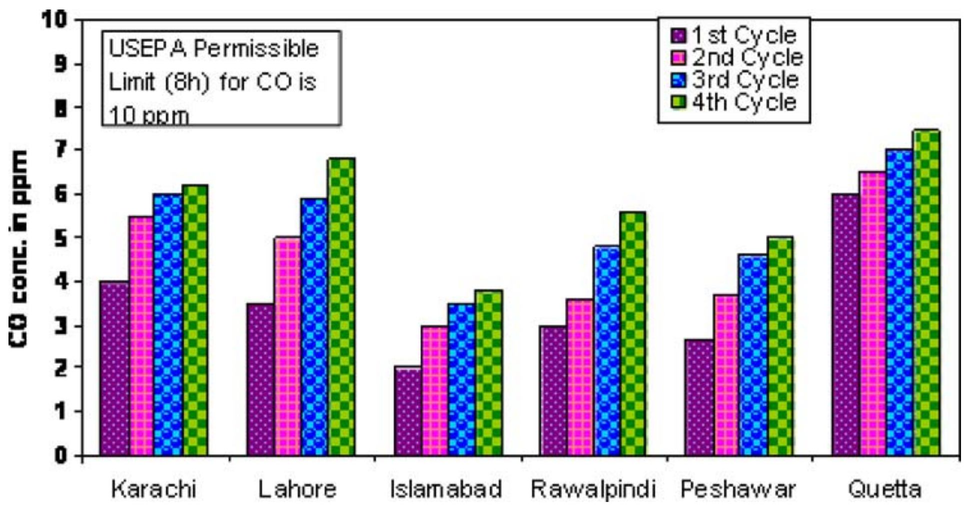

Fig. 9 Mean conc. of CO in six major cities of Pakistan

Since 1980 the maximum growth has been noted in 2-stroke vehicles i.e delivery vans which are 1190%, followed by Motor cycles 634% and Rickshaws 192%. Diesel trucks and buses have also increased at an alarming rate of 200–300% since 1980. Diesel vehicles due to overloading, faulty injection nozzles and weak engines emit excessive graphitic carbon (visible smoke). Available diesel in local market contains $1 \sim 1.5\%$ sulphur (NTRC, 1995).

Comparatively low sulphur dioxide was recorded at Karachi as compared to that at Lahore and Quetta. Although vehicle emission estimates show that a considerable amount of SO_2 is being emitted every-day at Karachi due to larger number of diesel vehicles being operated in the city, but due to well established sea breeze pattern of the city even the road side levels of SO_2 were observed well within specified limits of US EPA of 140 ppb as 24 hr. In addition to diesel fueled

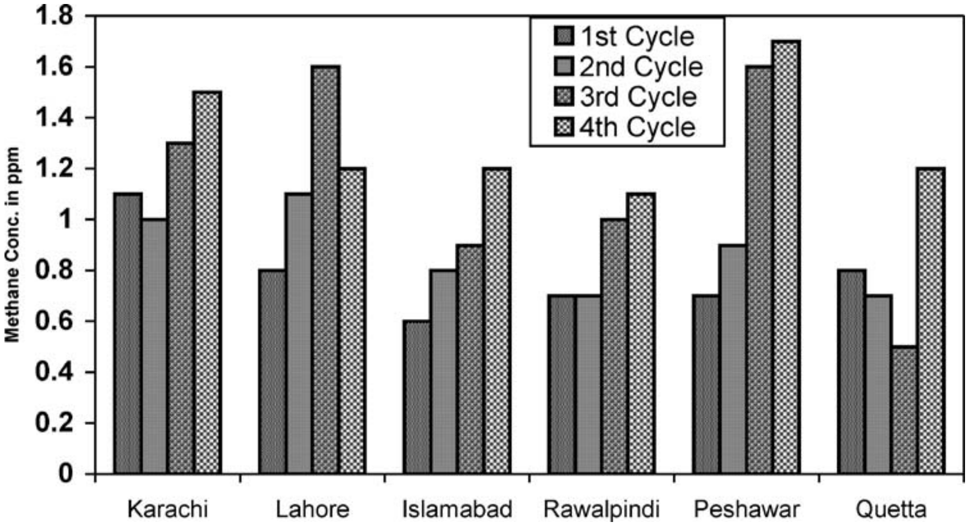

Fig. 10 Mean conc. of methane in six major cities of Pakistan

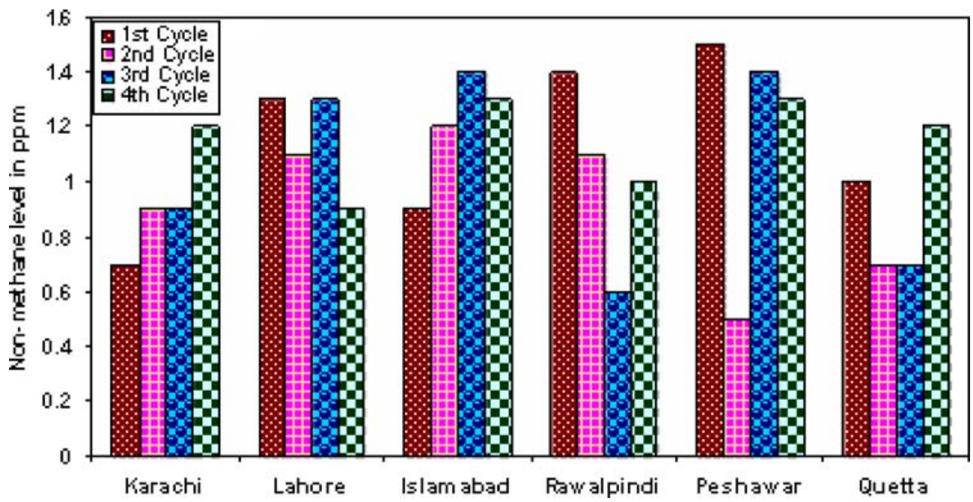

Fig. 11 Mean on non methane in six major cities of Pakistan

vehicles, a number of brick kilns are being operated around Lahore, Peshawar and Islamabad (which burn high sulphur coal) also contribute to ambient SO_2 concentration. It has also been reported (Hameed *et al.*, 2001) that coal based power plants across the border contribute towards increasing SO_2 levels in northeastern Pakistan.

In recent years attention has also been drawn towards the concentration of surface ozone. Eye irritation and increased number of asthmatic attacks are attributed to photochemical oxidant levels around 200 ug/m^3 (0.1 PPM). Most of the ozone in the troposphere (lower sphere) is formed indirectly by the action of sunlight on nitrogen dioxide. In addition to ozone (O_3), photo chemical reactions produce a number of oxidants including peroxyacetyl nitrates (PAN), nitric acid and hydrogen per oxide. Figure 8 shows the surface mean ozone levels in the six cities, which are well within prescribed USEPA limit of 120 ppb. Surface ozone has shown marked afternoon maximum at all sampling sites between 1200–1500 h irrespective of climatic conditions and site location. The surface ozone ranged from 6–41 ppb at Karachi, 8.5–45 ppb at Lahore, 6.2–32 ppb at Islamabad, 11–25 ppb at Quetta, 3.3–33.5 ppb at Rawalpindi, and 4–46 ppb at Peshawar.

Peak ozone levels were seen dependent on seasonal temperatures and observed numbers of sunny days in a particular city besides availability of its precursors. There has been 50–60 % rise in ozone levels in summer compared to winter and monsoon months when solar insolation is week. In Karachi the carbon monoxide levels in the ambient air on the average were found varying from 3 ppm to 14 ppm along the busy urban streets. The max. (1 h) carbon monoxide exceeded the recommended limit about 10% to 30 % at Lahore, Karachi and Quetta. Though CO demonstrated a diurnal cycle at all the monitoring sites, but a minimum CO level always prevailed with or without traffic indicating contribution from indiscriminate burning of solid waste in urban areas. The maximum CO concentration (14 ppm) was observed at Quetta. However mean CO concentration was found within the permissible limit (10 ppm) in all the six major cities (Fig. 9). CO varied as 1.3–12 ppm at Lahore, 1.5–5.2 ppm at Islamabad, 1.6–13 ppm at Karachi, 1.6–8 ppm at Rawalpindi and 2–10 ppm at Peshawar.

Hydrocarbon (Methane & Non Methane) levels were also measured at all sampling sites in six cities. The 48 h average concentration of hydrocarbon (methane & non-methane) in six cities are presented in Figs. 10 and 11 respectively.

The maximum HC level for methane was observed exceeding the prescribed US EPA limit of 0.24 ppm at most of study sites. The observed range of HC (Methane) was 0.25–2.8 ppm at Karachi, 0.45–2.2 ppm at Lahore, 0.3–1.7 ppm at Islamabad, 0.20–1.3 ppm at Quetta, 0.1–1.3 ppm at Rawalpindi, and 0.2–2.8 ppm at Peshawar, while HC (Nonmethane) ranged from 0.1–3.2 ppm at Karachi, 0.6–2.5 ppm at Lahore, 0.4–2.2 ppm at Islamabad, 0.4–1.6 ppm at Quetta, 0.6–1.8 ppm at Rawalpindi, 0.1–1.9 ppm at Peshawar. The main source of H-Cs (non-methane) in air has been evaporative losses and leakages from ill-maintained vehicles and storage facilities. Natural gas (mostly methane) is main fuel being used in industry, as CNG in vehicles and in day to day cooking. Frequent leakage is mainly responsible for higher methane levels. Biogenic methane could also be contributing since significant agricultural cultivation is being practiced around urban areas. Swampy area exists along the coastal belt.

The exceptionally high HC (non methane) upto 6 ppm was recorded at Karachi just after an oil spill from an accident of oil tanker Tasman Spirit at coastal belt of Karachi on 13th August 2003.

Although noise is a significant environmental problem, but it is often difficult to quantify its associated costs. The social costs of noise identified as productivity loss due to poor concentration, communication difficulties or fatigue due to insufficient rest. The biggest source of noise pollution that affects most people is from transport sector. According to NEQS (Pakistan's National Environmental Quality Standards) the level of vehicular noise should not exceed beyond 85 decibels (dB) at a distance of 7.5 m from source. Maximum noise level was seen approaching 100 dB at road sides especially in Karachi. In Lahore the max. sound level was recorded as 90.75 dB, at Rawalpindi and Peshawar the maximum level was 85 dB, the comparatively low level was found at Quetta (83.2 dB) and Islamabad (82 dB).

Conclusion

Concentrations and seasonal variations of all the criteria air pollutants i.e. particulate matter (TSP, PM10), CO, NO_x, SO_2, O_3, as well as traffic count were determined in major urban centers of the country. The study established the air quality baseline. The levels of TSP and other parameters were higher in summer (May–June) than in winter and monsoons, which can easily be interpreted in terms of time dependent changes primarily in meteorological conditions. The hourly and daily mean concentrations were compared with USEPA and NEQS prescribed limits. The high concentrations of CO, NO_x and HCs are related to excessive generation of the gases due to high volume of traffic congestions at intersections. The particulates levels as monitored in different cities contain a significant amount of vehicular soot besides crustal dust, especially in Lahore and Quetta. Highest particulate load was found at Lahore. Quetta city has been 2nd polluted city in term of TSP load. The TSP level in these cities are 2–3.6 times higher than the standard limits of USEPA (260 ug/m3). Similarly PM10 were maximum in Lahore and Quetta, which is not only due to poorly maintained vehicles, traffic jams, poor engine condition and fuel quality, but also due to inadequate vertical mixing and calm winds. The microscopic inhalable particles can affect breathing and respiration, cause lung damage and possibly cause premature death in children and elder people. High levels of particulates especially PM10 and gases were also attributed to large number of 2 stroke vehicles (60 to 75% gasoline vehicles were motorcycles) and adulteration of petrol/diesel and lube oil. Maximum NO_x varied from 37 ppb to 58 ppb recorded at major intersections of the cities. Sulpur dioxide and Ozone levels at all sites were with in USEPA limits. Carbon monoxide constituted the greatest mass of any air pollutant, followed by sulphur dioxide, hydrocarbons, nitrogen oxides and particulates. Its maximum levels have been recorded alarmingly high, ranging from 3 ppm to 14 ppm along the busy urban streets. Maximum methane and non-methane levels were observed exceeding the prescribe limit of 0.24 ppm at most of study sites. Maximum street noise level (95 dB) has been observed at Karachi and Lahore.

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