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32	Abstract	Background and purpose: Pakistan, during the last decade, has seen an extensive escalation in population growth, urbanization, and industrialization, together with a great increase in motorization and energy use. As a result, a substantial rise has taken place in the types and number of emission sources of various air pollutants. However, due to the lack of air quality management	

capabilities, the country is suffering from deterioration of air quality. Evidence from various governmental organizations and international bodies has indicated that air pollution is a significant risk to the environment, quality of life, and health of the population. The Government has taken positive steps toward air quality management in the form of the Pakistan Clean Air Program and has recently established a small number of continuous monitoring stations. However, ambient air quality standards have not yet been established. This paper reviews the data being available on the criteria air pollutants: particulate matter (PM), sulfur dioxide, ozone, carbon monoxide, nitrogen dioxide, and lead.

Methods: Air pollution studies in Pakistan published in both scientific journals and by the Government have been reviewed and the reported concentrations of PM, SO₂, O₃, CO, NO₂, and Pb collated. A comparison of the levels of these air pollutants with the World Health Organization air quality guidelines was carried out.

Results: Particulate matter was the most serious air pollutant in the country. NO₂ has emerged as the second high-risk pollutant. The reported levels of PM, SO₂, CO, NO₂, and Pb were many times higher than the World Health Organization air quality guidelines. Only O₃ concentrations were below the guidelines.

Conclusions: The current state of air quality calls for immediate action to tackle the poor air quality. The establishment of ambient air quality standards, an extension of the continuous monitoring sites, and the development of emission control strategies are essential.

33	Keywords separated by ' - '	Criteria air pollutants - Particulate matter - Pakistan
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4 **The state of ambient air quality in Pakistan—a review**

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8

9 **Abstract**

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of the continuous monitoring sites, and the development of 44
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Keywords Criteria air pollutants · Particulate matter · 46
Pakistan 47

1 Background and purpose 48

Over the last decade, the Asian countries have undergone a 49
substantial growth in development and urbanization coupled 50
with motorization and increase in energy use. A considerable 51
rise has occurred in the types and number of emission sources 52
of air pollutants in the region (Gurjar et al. 2008). Intense 53
industrial activity, large population, and unprecedented rise 54
in motor vehicle usage are posing severe environmental 55
impact in the region (Hopke et al. 2008). As a consequence, 56
air pollution has emerged as a significant threat to the 57
environment, quality of life, and health of the population in 58
Asia, especially in South Asia where emission control 59
technologies and strategies are not always being adopted. 60
Considerable evidence is available that poor air quality is 61
playing havoc with the health of the population in the region 62
(WHO 2002a). Urban air pollution is estimated to be 63

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64 responsible for 865,000 premature deaths every year and
65 about 60% of these deaths occur in Asia (World Health 2007).
66 Elevated concentrations of pollutants have been found in
67 various countries throughout Asia : India (Jain and Khare
68 2008; Oanh et al. 2006), Bangladesh (Begum et al. 2006),
69 Thailand (Oanh et al. 2006; Oanh and Zhang 2004/06),
70 Philippines (Cassidy et al. 2007; Oanh et al. 2006), Malaysia
71 (Omar et al. 2007), Korea (Pandey et al. 2008), Vietnam
72 (Oanh et al. 2006), Indonesia (Oanh et al. 2006), and China
73 (Chan and Yao 2008). High levels of particulate matter
74 (PM_{2.5}, PM₁₀) were reported in six Asian cities (Bandung,
75 Bangkok, Beijing, Chennai, Manila, and Hanoi) by Oanh
76 et al. (2006) within the framework of the Asian regional
77 air pollution research network. The average concentra-
78 tions of PM_{2.5} and PM₁₀ were in the range 44–168 and
79 54–262 µg/m³ in the dry season, and 18–104 and
80 33–180 µg/m³ in the wet season, respectively. An ongoing
81 study by the Clean Air Initiative for Asian Cities (CAI-
82 Asia 2006) shows that for 20 mega-cities in Asia, on
83 average, total suspended particulate (TSP) and PM₁₀ has
84 decreased from 1993 to 2004, but ambient levels remain
85 above the WHO guidelines. An analysis on a per city basis
86 suggests that particulate matter is the pollutant of concern
87 to most of the cities. Recently, Gurjar et al. (2008)
88 evaluated the air quality of 18 mega-cities (cities of about
89 10 million or more inhabitants) in the world and
90 categorized five as having ‘fair’ air quality and 13 as
91 ‘poor’. They suggested a multi-pollutant index (MPI)
92 which takes into account the combined level of the three
93 World Health Organization criteria pollutants (TSP, SO₂,
94 and NO₂). Dhaka, Beijing, Cairo, and Karachi emerged as
95 the mega-cities with the highest MPI. Karachi, one of the
96 mega-cities of Pakistan, appeared as the most polluted city
97 in the world with respect to TSP and held fourth position
98 on the MPI-based ranking. This clearly reflects the
99 severity of air pollution in Pakistan, where very little, so
100 far, has been done on air quality management. With
101 approximately 35% of the population residing in towns
102 and cities, Pakistan is the most urbanized country in South
103 Asia.

104 Many Government departments and international organ-
105 izations have identified degradation of ambient air quality
106 as a major environmental concern in Pakistan. Industrial
107 pollution, suspended particulates, indoor air pollution, and
108 increasing traffic trends were reported as key sources
109 affecting ambient air quality in the country (Pak-EPA
110 2005; Pakistan Economic Survey Report 2006–2007;
111 World Bank 2006b; Pakistan Millennium Development
112 Goals Report 2005). Over the last 20 years, the number of
113 motor vehicles has risen from 0.8 million to nearly 5
114 million; an average growth rate in excess of 14%. The
115 highest rise was in two-stroke vehicles (1,751%) while diesel
116 vehicle numbers were three times higher in 2005 than in 1980

(World 2006a). The mass-transit system in urban centers is
very poor and plays a major role in deterioration of urban air
quality. Aziz and Bajwa (2004) have emphasized the use of
alternate fuels, improved traffic management, a greater role
of the mass-transit system, and effective emission control for
two- and three-wheelers as means of improving air quality.
Further to this, they established a strong correlation between
air pollution and patients with respiratory diseases. In
Lahore, cases of coronary obstructive pulmonary disease
saw a sharp rise over the period 1999–2002. In addition, it
was calculated that inappropriate running of the mass-transit
system in Lahore was responsible for 23–26% of excess CO
(Aziz and Bajwa 2007) and it has been shown that a strong
correlation exists between the mass-transit system and urban
air pollution (Aziz and Bajwa 2008). Hyder et al. (2006)
reviewed the impact of road transport and its impacts on
health in Pakistan and pointed out that despite the three
national health policy documents, there was no approved
transport policy. Furthermore, the plans of the Environment
Protection Agency had been mentioned as ‘ambitious’ but
without practical projects and implementation, which
resulted in ever increasing air pollution in Pakistan.

In 1998, Pakistan, along with seven other South Asian
countries, signed the Malé Declaration on Control and
Prevention of Air Pollution and its Likely Transboundary
Effects for South Asia. The baseline study for the Male
Declaration pointed out that the incipient nature of
environmental regulation and management in Pakistan’s
industry is reflected in the lack of a proper, comprehensive,
and effective air quality monitoring capability that can be
used to track and address specific instances of air pollution
and air quality degradation. Little has actually been done
and the current air quality monitoring framework and
facilities are wholly inadequate in scale, technical capacity,
and operational methods. Qadir (2002) identified that poor
understanding of air quality management system by
planners, lack of provided resources, trained staff and
implementation mechanisms, fuel adulteration, poor vehicle
maintenance and urban mass-transport system, absence of
continuous monitoring stations, and ambient air quality
standards are the biggest constraints on development of
an effective air quality management system in the country.

As part of the 5-year plan for 2005–2010, the Pakistani
Government published the Pakistan Clean Air Program
(PCAP) for improving ambient air quality. The PCAP
highlighted vehicular emissions, industrial emissions, burn-
ing of solid waste and natural dust as major sources of
urban air pollutants in Pakistan and proposed a number of
short and long-term measures that require action at all
levels of government. Little has actually been done and the
current air quality monitoring framework and facilities are
wholly inadequate in scale, technical capacity, and opera-
tional methods. It was not until March 2007 that the

170 Pakistan Environment Protection Agency commenced the
 171 operation of the first Malé Declaration monitoring site in
 172 Bhawalnagar, Punjab measuring PM₁₀, TSP, SO₂, and NO₂.
 173 In March 2007, under grant in aid from the Government of
 174 Japan, continuous monitoring was instigated in Karachi,
 175 Lahore, Quetta, Peshawar, and Islamabad.
 176 The Pakistan Economic Survey Report 2006–2007
 177 stated that Pakistan was suffering from deterioration of air
 178 quality due to high population growth, absence of public
 179 transport and a great increase in private vehicles. The
 180 Pakistan Strategic Country Environmental Assessment
 181 World Bank Report (World Bank 2006b) identified
 182 particulate pollution as a serious environmental health
 183 concern and responsible for 22,000 premature deaths
 184 among adults and 700 deaths among children, with the
 185 total annual health burden due to PM being 1% of the
 186 gross domestic product (Table 1). In terms of annual
 187 DALYs lost, mortality accounts for an estimated 60%,
 188 followed by respiratory symptoms. This report recognized
 189 vehicular emissions, industrial pollution, and burning of
 190 municipal waste as principal sources of particulate
 191 pollution.
 192 This review is an attempt to gather all the existing
 193 information on air quality in Pakistan and mainly concen-
 194 trates on ambient air pollution studies published in both
 195 scientific journals and by the Pakistani Government. It
 196 focuses on the reported concentrations of six criteria
 197 pollutants: particulate matter, sulfur dioxide (SO₂), nitrogen
 198 dioxide (NO₂), ozone (O₃), carbon monoxide (CO), and
 199 lead (Pb). In addition, to emphasize the various pollution
 200 sources, details of the chemical composition of particulate
 201 matter are briefly discussed.
 202 In Europe, North America, Latin America, Oceania,
 203 and in many Asian counties there are ambient air quality
 204 standards for air pollution. However, there are no
 205 ambient air quality standards in Pakistan. In the absence
 206 of such standards, the levels of various air pollutants
 207 have been evaluated by their comparison with the WHO
 208 (2002b, 2006) air quality guidelines. This not only gives
 209 an insight to the current situation of air quality in the
 country but also helps identify and prioritize future studies
 and regulatory plans.

2 Pakistan

2.1 Geography

Pakistan is located in the north-western part of the South
 Asian subcontinent positioned between 23° 35' to 37° 05'
 North and 60° 50' to 77° 50' East and covers an area of
 796,095 km². Pakistan borders Iran on the west, Afghanistan
 to the northwest, China to the northeast, India to the east, and
 the Arabian Sea to the south. (Figure 1) It has four provinces
 namely Sindh, Punjab, North West Frontier Province, and
 Balochistan. The land is divided into three major geographic
 areas: the Northern Highlands; the Indus River plain, and the
 Balochistan Plateau. The country has an agricultural econo-
 my with a network of canals irrigating major parts of its
 cultivated land. Pakistan lies in the temperate zone with
 average rainfall of 80 mm in the south and 1,600 mm in the
 south (Pak-EPA 2005). The northern high mountainous
 ranges are extremely cold in winter while the summer
 months are pleasant. The plains of the Indus valley are
 extremely hot in summer and cold and dry weather in winter.
 The coastal southern strip alongside the Arabian Sea has a
 moderate climate.

2.2 Population and environment

The population of Pakistan is growing rapidly as
 according to the 1998 census, it was 132.35 million but
 the estimated figure for 2007 was 158.2 million (Pakistan
 Statistical Year Book 2007). It has the world's sixth
 largest population. This population explosion is a major
 force to environmental health degradation along with
 widespread industrialization coupled with urbanization
 resulting into dense urban centers. According to the
 Pakistan Economic Survey, 2006–2007, poverty together
 with proliferating population and rapid urbanization is

t1.1 **Table 1** Estimated annual health impacts due to urban air pollution (PM) in terms of annual cases and disability adjusted life years (DALYs) in Pakistan

Health end-points	Attributed total cases	Estimated annual DALYs	t1.2
Premature mortality adults	21,791	163,432	t1.3
Mortality children under 5	658	22,385	t1.4
Chronic bronchitis	7,825	17,215	t1.5
Hospital admissions	81,312	1,301	t1.6
Emergency room visits/outpatient hospital visits	1,595,080	7,178	t1.7
Restricted activity days	81,541,893	24,463	t1.8
Lower respiratory illness in children	4,924,148	32,007	t1.9
Respiratory symptoms	706,808,732	53,011	t1.10

Data from (World Bank 2006b)



Fig. 1 Political map of Pakistan

244 leading to immense pressure on the environment. The
 245 major urban centers are shown in Fig. 1.

246 **3 Ambient air quality measurements**

247 **3.1 Particulate matter**

248 The first reported particulate matter measurements in
 249 Pakistan were made at a suburban residential and commer-
 250 cial city center site in Lahore during 1978–1980 under the
 251 Global Environment Monitoring System (GEMS). The
 252 annual mean level of suspended particulate matter (SPM)
 253 at the commercial city center was $332 \mu\text{g}/\text{m}^3$ during 1978.
 254 At the suburban residential site, a concentration of 749 and
 255 $690 \mu\text{g}/\text{m}^3$ was reported during the period of 1979 and
 256 1980, respectively (WHO 1984). Later on, GEMS was
 257 extended with the inclusion of additional cities and
 258 pollutants monitored. This additional data was included in
 259 the 1992 report by the WHO/UNEP on urban air pollution
 260 in mega-cities of the world (WHO/UNEP 1992). The
 261 annual mean SPM concentration at the Space and
 262 Atmospheric Research Center in Karachi was $239 \mu\text{g}/\text{m}^3$
 263 in 1985 and this rose consistently during 1986, 1987, and
 264 1988 with the values of 265, 275, and $328 \mu\text{g}/\text{m}^3$
 265 respectively. In Karachi, at the Sindh Industrial Trading

Estate and Sadar, the annual mean SPM concentrations 266
 during 1987 and 1988 were 254 and 459 and 333 and 267
 $397 \mu\text{g}/\text{m}^3$, respectively. An ambient pollution survey 268
 carried out by Ghauri et al. (1992a), 1994) at 13 sites in 269
 Karachi for 15 consecutive days during May 1990 270
 reported that the daily mean TSP concentrations were 271
 240 ± 62 (March), 230 ± 55 (May) and $260 \pm 57 \mu\text{g}/\text{m}^3$ 272
 (June). In another study by Smith et al. (1996) for a year 273
 during 1992–1993 at three sites (city, industrial, and rural) 274
 in Lahore, the annual mean levels of TSP for the city, 275
 industrial, and rural sites were 607, 590, and $838 \mu\text{g}/\text{m}^3$ 276
 respectively. Parekh et al. (2001) reported TSP in Karachi 277
 and Islamabad over the period of 10 December 1998 to 278
 8 January 1999. They quote average daily TSP concen- 279
 trations at Karachi in the range $627\text{--}928 \mu\text{g}/\text{m}^3$ while those 280
 at Islamabad were between 428 and $998 \mu\text{g}/\text{m}^3$. The 281
 average levels of PM_{10} measured by Hashmi and Khani 282
 (2003) with a mobile monitoring laboratory at the Sindh 283
 Industrial Trading Estate and Korangi Industrial Area 284
 (Karachi) were 176.5 and $147.2 \mu\text{g}/\text{m}^3$, respectively. The 285
 hourly average PM_{10} concentration at Port Qasim in 286
 Karachi for 7 days during November was $123.49 \mu\text{g}/\text{m}^3$ 287
 (Hashmi et al. 2005a) 288

In an industrial area of Islamabad from October 1998 to 289
 June 1999, Wasim et al. (2003) collected baseline data on 290
 particulate matter and reported that highest concentrations 291
 of TSP occurred in December (approximately $350 \mu\text{g}/\text{m}^3$). 292
 In another study in Islamabad during June to September 293
 2002, TSP was in the range of $18.5\text{--}218.6 \mu\text{g}/\text{m}^3$ with a 294
 mean of $150.5 \mu\text{g}/\text{m}^3$ (Shaheen et al. 2005a). An investiga- 295
 tion carried out by Rajput et al. (2005) on TSP levels and 296
 its chemical composition in industrial and residential areas 297
 of Islamabad during 1995 depicted that the levels of TSP in 298
 the industrial area ($297 \mu\text{g}/\text{m}^3$) were more than double those 299
 of the residential area ($133 \mu\text{g}/\text{m}^3$). The Pakistan Environ- 300
 ment Protection Agency (Pak-EPA) in collaboration with 301
 the Japan International Cooperation Agency (JICA) has 302
 carried out studies on air quality in various cities. A 2001 303
 report (Pak-EPA/JICA 2001a) describes air quality meas- 304
 urements in Lahore, Rawalpindi, and Islamabad. It states 305
 that highest hourly average levels of SPM were in Lahore 306
 ($895 \mu\text{g}/\text{m}^3$) followed by Rawalpindi ($709 \mu\text{g}/\text{m}^3$) and then 307
 Islamabad ($520 \mu\text{g}/\text{m}^3$). Investigations in Gujranwala and 308
 Faisalabad showed that TSP (24 average) peaked at 309
 $5,190 \mu\text{g}/\text{m}^3$ and $3,477 \mu\text{g}/\text{m}^3$, respectively (Pak-EPA/ 310
 JICA 2001b). A study conducted by the Environment 311
 Agency of Pakistan in Quetta reported levels of particulate 312
 matter at four different locations (two kerbside, one 313
 industrial, one residential). The concentrations of TSP, 314
 PM_{10} , and $\text{PM}_{2.5}$ varied between $385\text{--}1,778 \mu\text{g}/\text{m}^3$, 315
 $126\text{--}709 \mu\text{g}/\text{m}^3$ and $104\text{--}222 \mu\text{g}/\text{m}^3$, respectively (Pak- 316
 EPA 2007). Similarly, Waheed et al. (2005, 2006) reported 317
 PM concentrations in four cities and concluded that levels 318

319 of SPM in Gujranwala (53–649 $\mu\text{g}/\text{m}^3$), Faisalabad (111–
 320 435 $\mu\text{g}/\text{m}^3$), Rawalpindi (845–1,870 $\mu\text{g}/\text{m}^3$), and Lahore
 321 (1,128–1,870 $\mu\text{g}/\text{m}^3$) were exceedingly unhealthy. A simi-
 322 lar study was conducted by Qadir and Zaidi (2006) in
 323 Faisalabad. The average mass of TSP was 550 $\mu\text{g}/\text{m}^3$ with
 324 a range of 467–600 $\mu\text{g}/\text{m}^3$.

325 During a study on trace metals in ambient air of Islamabad,
 326 the size fraction of particulate matter in four size fractions
 327 (<2.5, 2.5–10, 10–100, and >100 μm) was reported by Shah et
 328 al. (2004a,b, 2006b). In all the studies, they found the highest
 329 volume % fraction (more than 50%) was in the 10–100- μm
 330 size range followed by 2.5–10 μm . In two other studies on
 331 the same topic in Islamabad, Shaheen et al. (2005b) also
 332 reported on four size fractions while Shah and Shaheen
 333 (2007a,b) used nine size fractions. Shaheen et al. (2005b)
 334 found similar results to those of Shah et al. (2004a,b, 2006).
 335 Shah and Shaheen (2007a) reported that the dominant
 336 fraction was 5–10 μm .

337 Recently Ghauri et al. (2007) presented the results of a
 338 year-long baseline air quality study conducted by the
 339 Pakistan Space and Upper Atmosphere Research Com-
 340 mission (SUPARCO) during 2003–2004. The measure-
 341 ments were carried out by two mobile pollution
 342 monitoring labs at an interval of 15 min for 48 h at each
 343 site. A total of 33 sites were monitored four times
 344 (monsoon, winter, spring, summer) during the period.
 345 The survey was carried out in six major urban cities:
 346 Karachi (ten sites), Lahore (seven sites), Quetta (three
 347 sites), Rawalpindi (five sites), Islamabad (three sites),
 348 and Peshawar (five sites). With reference to TSP (1 h
 349 maximum), in Lahore, the concentration reached 996 $\mu\text{g}/\text{m}^3$
 350 while the concentrations in other cities were still
 351 elevated: Quetta (778 $\mu\text{g}/\text{m}^3$), Peshawar (530 $\mu\text{g}/\text{m}^3$),
 352 Rawalpindi (500 $\mu\text{g}/\text{m}^3$), Islamabad (490 $\mu\text{g}/\text{m}^3$), and
 353 Karachi (410 $\mu\text{g}/\text{m}^3$). However, these cities displayed a
 354 slightly different pattern for PM_{10} (1 h maximum) with
 355 concentrations decreasing from Lahore (368 $\mu\text{g}/\text{m}^3$),
 356 Peshawar (350 $\mu\text{g}/\text{m}^3$), Quetta (331 $\mu\text{g}/\text{m}^3$), Karachi
 357 (302 $\mu\text{g}/\text{m}^3$), Islamabad (280 $\mu\text{g}/\text{m}^3$), to Rawalpindi
 358 (276 $\mu\text{g}/\text{m}^3$). The ambient air quality along the National
 359 Highway of Pakistan was monitored by Ali and Athar
 360 (2008). The monitoring was carried out at nine sites along
 361 three sections of the highway and reported PM_{10} varied
 362 from 123 to 443 $\mu\text{g}/\text{m}^3$. Shah and Shaheen (2007b) carried
 363 out measurement of TSP (May 2003 to April 2004) and
 364 quote an average TSP concentration for Islamabad of
 365 151.9 $\mu\text{g}/\text{m}^3$. In an investigation on TSP and heavy
 366 metals in airborne particulate matter in Islamabad Shah
 367 and Shaheen (2008) reported on the results of measure-
 368 ments during June 2004 to May 2005. The concentration
 369 of TSP in Islamabad varied from 41.8 to 977 $\mu\text{g}/\text{m}^3$ with a
 370 mean of 164 $\mu\text{g}/\text{m}^3$ over the year. The concentration of
 371 $\text{PM}_{2.5}$ in Lahore has been reported by Husain et al.

(2007b). This campaign was undertaken during November
 2005–February 2006 and levels were in the range
 53–476 $\mu\text{g}/\text{m}^3$. Hopke et al. 2008 reported levels of
 $\text{PM}_{2.5}$ and PM_{10} at Nilore (Islamabad) from 2002 to
 2005. The mean concentrations of $\text{PM}_{2.5}$ and PM_{10} over
 the 4 years were 15 and 68 $\mu\text{g}/\text{m}^3$ with a standard
 deviation of 10 and 50, respectively. The relatively low
 levels of particulate matter are most likely due to the
 location; a residential campus away from major emission
 sources.

Figure 2 shows typical PM_{10} and TSP concentrations for
 various cities in Pakistan. From this, it is clear that the
 country is facing alarming levels of particulate matter. The
 dry climate, soil erosion, lack of roadside vegetation and
 paved areas, substantial rise in number of vehicles, poor
 mass-transit system, and excessive automobile emissions
 from old and poorly maintained vehicles have all been held
 responsible. Higher levels of PM are generally found in
 summer rather than winter and the monsoon. Ilyas (2006)
 describes a study into the amount of smoke released by
 various vehicles during an air pollution survey in Quetta.
 He concluded that trucks (0.56 g/s) emitted the highest
 quantity of smoke followed by rickshaws (0.43 g/s), busses
 (0.23 g/s), wagons (0.14 g/s), cars (0.05 g/s), and auto-
 cycles (0.02 g/s). In recent years, the government has tried
 to tackle the excessive concentration of PM by encouraging
 the use of compressed natural gas (CNG) rather than petrol
 or diesel. Pakistan is the largest CNG-using country in Asia
 and the third largest in the world. (The Pakistan Millennium
 Development Goals Report 2005). Nonetheless, the present
 24-h mean levels of particulate matter in various cities are
 at least three to five times higher than the WHO guidelines
 of 50 $\mu\text{g}/\text{m}^3$ as a 24-h mean.

3.1.1 Comparison with other cities in the world

As shown in Table 2, a comparison of annual PM levels in
 different cities of Pakistan with other Asian cities indicates

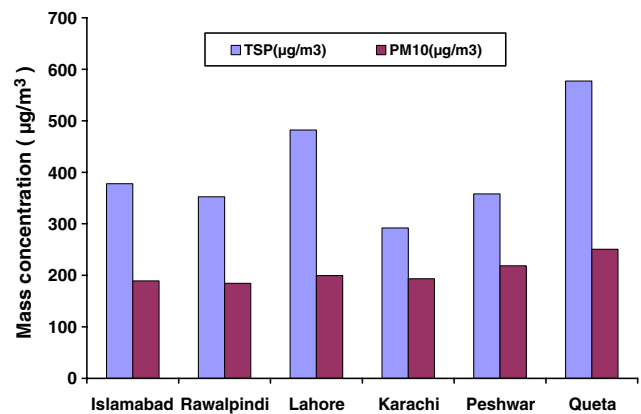


Fig. 2 Concentration of TSP and PM_{10} in different cities in Pakistan

t2.1

Table 2 Concentrations of annual particulate matter pollution in various Asian cities during 2004

City	Country	PM ₁₀ (µg/m ³)	Reference	t2.2
Bangkok	Thailand	60	PCD (2005) Thailand	t2.3
Singapore	Singapore	31	MOE&WR (2006)	t2.4
Tokyo	Japan	30	BOE (2005).	t2.5
Busan	South Korea	60	MOE (2006) South Korea	t2.6
Seoul	South Korea	61	MOE (2006) South Korea	t2.7
Daegu	South Korea	58	MOE (2006) South Korea	t2.8
Incheon	South Korea	62	MOE (2006) South Korea	t2.9
Jakarta	Indonesia	100	MOE (2005) Indonesia	t2.10
Surabaya	Indonesia	50	ADB&CAI-Asia (2006a)	t2.11
Manila	Philippines	40	ADB&CAI-Asia (2006b)	t2.12
Hanoi	Vietnam	112	Khaliqzaman (2005)	t2.13
Shanghai	China	100	Fu (2004)	t2.14
Beijing	China	140	BJEPB (2005)	t2.15
Hong Kong	China	59	EPD (2004) China	t2.16
Taipei	China	62	EPA (2007) Taiwan	t2.17
Kathmandu	Nepal	129	MOEST(2005) Nepal	t2.18
Colombo	Sri Lanka	80	Clean Air Sri Lanka (2006)	t2.19
Dhaka	Bangladesh	131	SDNP (2007)	t2.20
Kolkata	India	122	CPCD (2006)	t2.21
Mumbai	India	77	CPCD (2006)	t2.22
Patna	India	82	CPCD (2006)	t2.23
Jodhpur	India	109	CPCD (2006)	t2.24
Pune	India	137	CPCD (2006)	t2.25
Ahmedabad	India	138	CPCD (2006)	t2.26
Agra	India	133	CPCD (2006)	t2.27
Lucknow	India	157	CPCD (2006)	t2.28
Delhi	India	131	CPCD (2006)	t2.29
Islamabad	Pakistan	188	World Bank (2006c)	t2.30
Karachi	Pakistan	194	World Bank (2006c)	t2.31
Lahore	Pakistan	202	World Bank (2006c)	t2.32
Peshawar	Pakistan	202	World Bank (2006c)	t2.33
Quetta	Pakistan	250	World Bank (2006c)	t2.34
Rawalpindi	Pakistan	191	World Bank (2006c)	t2.35

408 that concentrations are generally higher in Pakistani
 409 cities. Gurjar et al. (2008) quote Karachi as the most
 410 polluted city in the world with respect to TSP. According
 411 to the World Bank Development Indicator (World Bank
 412 Development Indicator 2006), by 2002, PM₁₀ in Pakistan
 413 had fallen to 165 µg/m³ from 226 µg/m³ in 1990. These
 414 estimates were based on the Global Model of Ambient
 415 Particulates (GMAPS) and only Sudan (219 µg/m³) and
 416 Iraq (167 µg/m³) had higher levels than Pakistan. Howev-
 417 er, due to lack of historic continuous monitoring no
 418 consistent data sets are available to develop a clear
 419 temporal and spatial variation in PM. Based on the
 420 sporadic studies, an increasing trend in levels of PM
 421 appears more likely. GMAPS is an attempt by the World
 422 Bank to overcome the lack of monitoring information

423 through an econometrically estimated model for predicting
 424 PM levels in world cities. It cannot replace real-time
 425 monitoring. The recent baseline study by Ghauri et al.
 426 (2007) revealed that the levels of TSP and PM₁₀ in various
 427 cities were in the range of 292–577 and 189–251 µg/m³,
 428 respectively.

3.2 Sulfur dioxide 429

GEMS measurements from Lahore showed that the
 430 annual SO₂ concentration, in the city center, for 1978
 431 was 49 µg/m³ while 40 µg/m³ was recorded at a suburban
 432 residential area during 1979 (WHO 1984). In later studies,
 433 SO₂ was reported as 67–134 µg/m³ in the city center as
 434 compared to 25–67 µg/m³ at sites within the Karachi
 435

436 metropolitan area (WHO/UNEP 1992). These results were
 437 actually taken from the work of Ghauri et al. (1988). The
 438 bulk of the data was from a study undertaken during 12–13
 439 June 1988. Hashmi and Khani (2003) reported that levels of
 440 SO₂ at Korangi Industrial Area and Sindh Industrial Trading
 441 Estate (Karachi) were 7.4 and 24.9 μg/m³, respectively. At
 442 Port Qasim (Karachi) for 7 days during November, the
 443 concentration of SO₂ was 6.3 μg/m³ (Hashmi et al. 2005a).
 444 In another study, Hashmi et al. (2005b) analyzed concen-
 445 trations of SO₂ at five different stations in Karachi. Three
 446 stations were in an industrial area and one each in residential
 447 and downtown areas. Time-weighted average values were
 448 evaluated for 1 and 24 h and the maximum 24-h average of
 449 SO₂ was found at the industrial site (9.30 μg/m³) followed by
 450 downtown (0.98 μg/m³) and the residential area (0.24 μg/m³).

451 The Pakistan Environment Protection Agency indicated
 452 that the highest concentrations of SO₂ occurred in Lahore
 453 (115 μg/m³) followed by Rawalpindi (78.6 μg/m³) and
 454 Islamabad (73.4 μg/m³; Pak-EPA/JICA 2001a,b). The results
 455 of a year-long baseline air quality study conducted by
 456 SUPARCO during 2003–2004 (Ghauri et al. 2007) revealed
 457 that the concentrations of SO₂ were within the limits of the
 458 US-EPA standards. From their results, the 48-h mean
 459 concentrations of SO₂ in different cities were: Islamabad
 460 (52.4 μg/m³), Rawalpindi (41.9 μg/m³), Lahore (57.6 μg/m³),
 461 Karachi (57.6 μg/m³), Peshawar (57.6 μg/m³), Quetta
 462 (68.1 μg/m³). According to Ali and Athar (2008), the
 463 ambient SO₂ level over 72-h along the National Highway
 464 of Pakistan was 0.04–0.26 μg/m³.

465 The main sources of SO₂ have been shown to be power-
 466 generation plants, industrial process, and diesel-fueled
 467 vehicles. Diesel vehicle numbers were three times higher
 468 in 2005 than in 1980 (World 2006a). The current levels in
 469 various cities are two to three times higher than WHO air
 470 quality guideline value (20 μg/m³) for 24 h (WHO 2006).

471 **3.3 Ozone**

472 According to the GEMS study, the daily average of O₃ in
 473 Karachi was in the range 36–50 μg/m³ (WHO/UNEP 1992).
 474 Ghauri et al. (1992b) reported measurement of O₃ during
 475 1986–1988 at three sites (one upwind and two down-
 476 wind) in Karachi. The concentration at the upwind site
 477 was 2–50 μg/m³ and maximum levels at the downwind
 478 sites were 80 and 100 μg/m³. In another study in Karachi
 479 (Sindh Industrial Trading Estate) Yousufzai AH et al. (2000)
 480 performed continuous measurements of O₃ and found the
 481 lowest level of ozone was 15 μg/m³ rising to 38 μg/m³ during
 482 the day. The report by Pak-EPA/JICA (2001a) showed that
 483 levels of O₃ in Lahore, Rawalpindi, and Islamabad were 17,
 484 34, 20 μg/m³. Within Karachi levels at Port Qasim were
 485 24 μg/m³ while the maximum 8 hour average at industrial
 486 area, residential and downtown areas were 19, 13, 9.6 μg/m³,

487 respectively (Hashmi et al. 2005a,b). According to Ghauri et
 488 al. (2007), the 48-h mean concentration of ozone was highest
 489 in Karachi (50 μg/m³), followed by Quetta (48 μg/m³),
 490 Peshawar (46 μg/m³), Lahore (44 μg/m³), Islamabad
 491 (36 μg/m³), and Rawalpindi (34 μg/m³). Generally, maxi-
 492 mum levels were found in the afternoon and peak
 493 concentrations were recorded during the summer. The
 494 current levels of O₃ in the country are well within the
 495 WHO air quality guidelines (100 μg/m³ 8-h mean). How-
 496 ever, due to a marked rise in CNG vehicles, it is very
 497 likely that the concentration could increase substantially
 498 downwind of urban centers due to increases in vehicular
 499 NO₂ emissions.

500 **3.4 Carbon monoxide**

501 The first measurements of CO in Karachi were undertaken
 502 in 1969 as part of a survey at 26 road locations (Beg 1990).
 503 Concentrations were in the range 6–23 mg/m³ near the
 504 roadside and 12–41 mg/m³ in the center of the road during
 505 traffic congestion. In 1983, a survey from January to June
 506 showed levels of 12–23 mg/m³; but by 1988 CO
 507 concentrations had increased and 10-h means were in the
 508 range 2–57 mg/m³ with short-term concentrations up to
 509 107 mg/m³ near heavy trafficked sites. A WHO/UNEP
 510 report on urban air pollution in mega-cities of world
 511 (WHO/UNEP 1992) quoted concentrations in Karachi of
 512 2–7 mg/m³. However, it is worthy to note that lower levels
 513 of CO during this study are not comparable with other
 514 previous studies (e.g., Beg 1990). It is very unlikely that
 515 CO levels decreased sharply and the reported low levels
 516 could be due to differences in sampling sites. In another
 517 study in Karachi at 13 sites by Ghauri et al. (1992a, 1994)
 518 CO was in the range 10.4–11.5 mg/m³. According to the
 519 Environmental Protection Agency (Pak- EPA/JICA 2001)
 520 the concentrations of CO in Lahore, Rawalpindi, and
 521 Islamabad were 3.2 mg/m³, 2.1 mg/m³, and 1.8 mg/m³,
 522 respectively. Hashmi et al. (2005a,b) have reported CO
 523 concentrations at various sites across Karachi. The highest 8-
 524 h average CO was found in the industrial area 0.56 mg/m³
 525 followed by downtown 0.32 mg/m³ and the residential site
 526 0.14 mg/m³. Levels were slightly higher at Port Qasim
 527 (0.71 mg/m³; Hashmi et al. 2005a). The most recent results
 528 come from 2003–2004 by Ghauri et al. (2007). They found
 529 that Quetta had the highest concentrations (16.1 mg/m³). In
 530 addition to the hourly average, they also calculated the
 531 48-h mean. Again, Quetta (8.1 mg/m³) topped the list
 532 followed by Karachi (5.8 mg/m³), Rawalpindi, and Lahore
 533 (4.6 mg/m³) and Islamabad and Peshawar (3.5 mg/m³).

534 A large variation in CO levels have been quoted from
 535 different parts of the country, but generally higher concen-
 536 trations were reported close to busy urban streets and often
 537 the US-EPA 1-hr air quality standard (40 mg/m³) was

538 exceeded. The WHO guidelines cover a range of averaging
 539 times: 15 min—100 $\mu\text{g}/\text{m}^3$, 30 min—60 $\mu\text{g}/\text{m}^3$, 1 h—
 540 30 $\mu\text{g}/\text{m}^3$ (WHO 2002a). Based on the available evidence,
 541 it is very likely that the currents levels would be higher
 542 during the day in urban centers in comparison to these
 543 guidelines. The increase in number of vehicles and poor
 544 mass-transit system and solid waste burning are the
 545 principal contributors to soaring levels of CO. Aziz and
 546 Bajwa (2007) calculated that inappropriate running of the
 547 mass-transit system in Lahore was responsible for 23–26%
 548 of the excess CO. Almost 48,000 tonnes of solid waste is
 549 generated each day, most of which dumped and then burnt
 550 again contributing to CO (World Bank 2006b).

551 3.5 Nitrogen dioxide

552 The data included in a 1992 report (WHO/UNEP 1992)
 553 revealed that the daily average concentration of NO_2 in
 554 Karachi was 38–544 $\mu\text{g}/\text{m}^3$. Yousufzai et al. (2000) per-
 555 formed continuous measurements at the Sindh Industrial
 556 Trading Estate, Karachi and quoted values for NO and NO_x
 557 in the range of 13.3–131.4 and 32.3–35.9 $\mu\text{g}/\text{m}^3$, respec-
 558 tively. In a 2001 report (Pak-EPA/ JICA 2001), the
 559 concentrations of NO and NO_x in Lahore, Rawalpindi,
 560 and Islamabad were 165.4, 293.3; 129.7, 139.1; and 178.6,
 561 278.2 $\mu\text{g}/\text{m}^3$, respectively. Hashmi et al. (2005b) analyzed
 562 NO_2 concentrations within Karachi. The maximum 24-
 563 h average of NO_2 occurred at an industrial site (13 $\mu\text{g}/\text{m}^3$)
 564 while lower concentrations were recorded at residential
 565 (2.60 $\mu\text{g}/\text{m}^3$) and downtown sites (2.20 $\mu\text{g}/\text{m}^3$). More recent-
 566 ly, Pak-EPA declared NO_2 as the second most important
 567 emerging air pollutant in Pakistan and carried out a study to
 568 assess its concentration in five major cities (Karachi, Lahore,
 569 Quetta, Peshawar, Islamabad) in 2006. Both Karachi and
 570 Lahore had an average concentration of 76 $\mu\text{g}/\text{m}^3$, followed
 571 by Quetta (69 $\mu\text{g}/\text{m}^3$), Peshawar (47 $\mu\text{g}/\text{m}^3$) and Islamabad
 572 (30 $\mu\text{g}/\text{m}^3$; Pak-EPA/JICA 2006). Another similar study was
 573 carried out at 15 different locations (schools, roads) in
 574 Murree (a mountain resort) during 18–22 September, 2006.
 575 Results indicate that the highest concentration occurred on the
 576 road side (Mall Road 76.9 $\mu\text{g}/\text{m}^3$, Ghora Gali 74.4 $\mu\text{g}/\text{m}^3$)
 577 while the minimum was recorded at the High School
 578 (5.1 $\mu\text{g}/\text{m}^3$), 1 km away from a busy road. The concen-
 579 trations in Mall Road were attributed to the use of coal
 580 barbeques outside restaurants; traffic was responsible for
 581 the levels in Ghora Gali (Pak-EPA 2006). Ghauri et al.
 582 (2007) have reported that ambient concentrations of NO_x
 583 are increasing due to the introduction of CNG vehicles.
 584 The annual values derived from the 48-h mean of revealed
 585 that the current levels in the country are slightly higher
 586 than the WHO air quality guideline value of 40 $\mu\text{g}/\text{m}^3$
 587 (Ghauri et al. 2007). Although 1-h means have not been
 588 reported concentrations must have exceeded the WHO

guidelines (200 $\mu\text{g}/\text{m}^3$) as daily averages have been much
 larger than this figure. 589 590

3.6 Lead 591

Data for lead is predominantly available for Karachi and
 Lahore. Parekh et al. (1987) showed that mean concentra-
 tion of Pb in total suspended particulate matter and water-
 soluble component in ambient air of Karachi was 71 $\mu\text{g}/\text{m}^3$.
 An extension of the above work was carried out by Parekh
 et al. (1989) who discussed the results of three sampling
 campaigns. The first two (22–27 July, 1985; 18–26 March,
 1986) were conducted only at one suburban site and
 involved collection of TSP, while the third (27 Feb–6
 March, 1987) was undertaken at four different sites and
 particulate matter was collected in five different size ranges
 using an impactor. The four sites included a coastal site,
 an industrial area, suburban, and a steel mill. For the first
 two measurements the levels of Pb were 93 ng/m^3 and
 275 ng/m^3 , respectively. When the size fraction is
 considered (fine <1 μm and coarse 1–10 μm) the concen-
 trations across Karachi, in decreasing order, were subur-
 ban site (287 ng/m^3 ; 56 ng/m^3), industrial (214 ng/m^3 ;
 44 ng/m^3), steel mill (65 ng/m^3 ; 16 ng/m^3) and coastal
 (4.8 ng/m^3 ; 0.2 ng/m^3), respectively. Ghauri et al. (1994)
 used the same sites and reported concentrations for both
 TSP and <2- μm size fraction. The concentrations from the
 suburban, industrial, steel mill, and coastal sites for both
 TSP and <2 μm size were 593 and 568, 255 and 228, 85
 and 75, 3.3 and 2.1 ng/m^3 , respectively. In the same paper,
 they stated that the concentrations of Pb from two other
 sites in Karachi, during February, 1992, were 151 ng/m^3
 and 93 ng/m^3 . Smith et al. (1996) investigated various
 metals for a year during 1992–1993 at three sites (city,
 industrial, and rural) in Lahore. The concentrations of Pb
 were: city—3.92 $\mu\text{g}/\text{m}^3$, industrial—1.23 $\mu\text{g}/\text{m}^3$, rural—
 1.21 $\mu\text{g}/\text{m}^3$. 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623

Parekh et al. (2002) estimated that 391 metric tons/year
 of Pb was emitted into atmosphere at that time. It is notable
 that in 2001 the Pakistani Government encouraged all the
 refineries in the country to remove lead from petrol and
 from July 2002 petrol has been lead free (Paul et al. 2003).
 Saqib and Jaffar (2004) evaluated lead levels in Islamabad
 through high volume sampling and a dithizone-carbon
 tetrachloride scrubbing method. During this study the Pb
 levels found by the former technique were between 30–
 69 $\mu\text{g}/\text{m}^3$ whereas a range of 13–90 $\mu\text{g}/\text{m}^3$ was obtained by
 the latter technique. During a measurement of selected
 metals and their dependence on meteorological parameters
 by Shah et al. (2004a) during October 2001–March 2002 in
 Islamabad, the mean concentration of Pb was 22.8 ng/m^3
 with a range of 4–4,000 ng/m^3 . In a latter study in
 Islamabad during March–May 2002, Shah et al. (2004b)
 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639

640 reported that the mean concentration at a rural site was
 641 505 ng/m³ (range 4–4,075 ng/m³) compared to 185 ng/m³
 642 (range 16–4,000 ng/m³) for an urban site. Shaheen et al.
 643 (2005a) evaluated levels of Pb in airborne particulate matter
 644 over Islamabad during June to September 2002. They
 645 reported a mean concentration of 146 ng/m³ with a range of
 646 12–481 ng/m³. In an urban area of Islamabad, during
 647 October 2002 to May 2003 Shaheen et al. (2005b) report a
 648 mean value of 214 ng/m³ (range 3–4,000 ng/m³). Shah et
 649 al. (2006a) studied the distribution of Pb in TSP at 8 sites in
 650 Islamabad during June 2001 to January 2002 using high
 651 volume sampling. The mean concentration of Pb was
 652 210 ng/m³ (range of 37–5,979 ng/m³). An investigation
 653 on the spatial variation of metals and particle size
 654 distribution in TSP at a rural and urban site around
 655 Islamabad during November 2002–April 2003 was
 656 carried out by Shah et al. (2006b). This study revealed
 657 higher concentrations at the rural site (320 ng/m³)
 658 compared to the urban one (160 ng/m³). It was argued
 659 that rural site was close to a main road and, moreover, was
 660 downwind of the city center which lead to the heavy
 661 burden of Pb. The results of Shah and Shaheen (2007a)
 662 showed that during September 2003–March 2004 the
 663 mean concentration of Pb in Islamabad was 128 ng/m³
 664 with a range of 13–360 ng/m³.
 665 Shah and Shaheen (2007b) quoted an average of
 666 182 ng/m³ (range of 2–895 ng/m³) during May 2003–
 667 April 2004 in Islamabad. In another investigation on TSP
 668 and heavy metals in airborne particulate matter during
 669 June 2004–May 2005, in Islamabad, Shah and Shaheen
 670 (2008) showed that Pb ranged from 5–895 ng/m³ with a
 671 mean of 144 ng/m³. Saqib et al. (2007) extended their earlier
 672 work (Saqib and Jaffar 2004) on lead to Rawalpindi. Here,
 673 high volume sampling yielded values between 22 and
 674 57 µg/m³ while dithizone-carbon tetrachloride scrubbing
 675 indicated levels of 18 to 39 µg/m³. Again, these concen-
 676 trations are significantly higher than those reported by other
 677 workers. The atmospheric chemistry of Lahore was explored
 678 by Farhana and Husain (2006) during December 2005–
 679 January 2006 and reported levels of Pb were 12 µg/m³. In a
 680 study conducted by Qadir and Zaidi (2006) in Faisalabad,
 681 the reported levels of Pb were 549 ng/m³. Ghauri et al.
 682 (2007) year-long baseline air quality study during 2003–
 683 2004 revealed a very high concentration of Pb in Islamabad
 684 as compared to other cities of Pakistan. The reported mean
 685 48-h concentration in Islamabad was 73 µg/m³—not to
 686 dissimilar to the results of Saqib and Jaffar (2004). The
 687 mean 48-h levels in Lahore, Karachi, Peshawar, and Quetta
 688 were in the range of 2–5 µg/m³. The recent surveys in the
 689 country suggest that there has been a decrease in concentra-
 690 tion of Pb in ambient air since the removal of lead from
 691 petrol in 2002. However, despite the variability in docu-
 692 mented concentrations the current levels are still many times

higher than WHO (2002a) of 500 ng/m³ annual mean. The
 present high concentrations are most probably due to
 industrial activities such as iron and steel production, copper
 smelting and refining, and manufacture of lead-containing
 compounds. In a review paper on the status of children's
 blood lead levels in Pakistan, Kadir et al. (2008) concluded
 that although lead has been removed from petrol, most of the
 children still have high blood lead levels and soil close to
 roads may have been contaminated by past use of leaded
 petrol.

3.7 Other pollutants

During the studies on the evaluation of particulate
 matter, a variety of metallic components (e.g., Na, K,
 Fe, Zn, Pb, Mn, Cr, Co, Ni, Cd, Eu, Fe, Hf, Hg, K, La,
 Na, Sb, Sc, Se, black carbon, organic carbon, SO₄²⁻,
 NO₃⁻, Br, Cl, and NH₄⁺) were determined as well. Based
 on metallic and ionic composition emissions from oil and
 coal combustion, industrial processes, building construc-
 tion sites, biomass burning, and wind-blown soil were
 identified as the main sources. Details of the pollutants
 studied during these studies are summarized in Table 3,
 while Table 4 provides an example of typical concen-
 trations for the various criteria pollutants in the major
 cities in Pakistan.

It is evident from the review that the number of air
 pollution monitoring campaigns has increased over the
 years but it is only relatively recently that a national
 monitoring program has commenced. Monitoring stations
 were established in March 2007 and with two sites in
 both Karachi and Lahore and one site in Quetta,
 Peshawar, and Islamabad. In addition, three mobile
 stations are now in use in Karachi, Lahore, and Islam-
 abad. These sites measure particulate matter, hydro-
 carbons, O₃, CO, SO₂ and NO₂.


Ikram and Akram (2007) put forward a low-cost solution
 to urban air pollution monitoring in Pakistan through an
 internet-based network of volunteers (Volunteer Internet-
 based Environment Watch, VIEW). The design involved
 the use of data acquisition devices with the personal
 computers of the volunteers and transfer of the data to a
 central server. Initially, VIEW was implemented only in
 Lahore and Islamabad. Thirteen data acquisition devices for
 temperature, humidity, and carbon monoxide were
 deployed in Lahore and eight in Islamabad. Overall, this
 pilot project established the possibility of a low-cost
 solution to urban air pollution monitoring in low-income
 countries. The system was never fully tested due to
 technological and financial constraints.

It is evident from the data in Table 3 that a number of
 different pollutants have been investigated and most
 indicate that air pollution is a serious problem in Pakistan.

t3.1 **Table 3** Summary of air quality monitoring studies in Pakistan

t3.2	Authors	Pollutants	Area	Duration	Isl	Raw	Lah	Fai	Sia	Gug	She	Kar	Pes	Que	N A
t3.3	WHO (1984)	SPM, SO ₂	Urban/ Suburban	1979–1990	-	-	+	-	-	-	-	-	-	-	-
t3.4	Parekh et al. (1987)	Metals, SO ₄ ⁻² , NO ₃ ⁻ , Cl	Urban	22–27 July, 1985	-	-	-	-	-	-	-	+	-	-	-
t3.5	Parekh et al. (1987)	Metals	Seaside, Industrial, Urban,	27 Feb. -6 March 1986	-	-	-	-	-	-	-	+	-	-	-
t3.6	Beg (1990)	CO	Urban		-	-	-	-	-	-	-	+	-	-	-
t3.7	WHO/UNEP (1992)	CO, NO ₂ , O ₃ , SO ₂ , SPM	Urban	12–13 June, 1988	-	-	-	-	-	-	-	+	-	-	-
t3.8	Ghauri et al. (1992)	CO, NO _x , O ₃ , TSP	Urban		-	-	-	-	-	-	-	+	-	-	-
t3.9	Qadir et al. (1992)	Trace metals	Industrial	Sep. 1989– Jan.1998	-	-	-	-	-	-	+	-	-	-	-
t3.10	Ghauri et al. (1994)	CO, NO ₂ , O ₃ , Pb, TSP	Urban	May 1990 (15 days)	-	-	-	-	-	-	-	+	-	-	-
t3.11	Qadir et al. (1995)	Metals			+	+	+	+	-	-	-	-	-	-	-
t3.12	Smith et al. (1995)	PAHC – Road dust/soil	Urban		-	-	+	-	-	-	-	-	-	-	-
t3.13	Smith et al. (1996)	PAH, EC, OC, Metals	Urban		-	+	-	-	-	-	-	-	-	-	-
t3.14	Harrison et al. (1997)	TSP, SO ₄ ⁻² , NO ₃ ⁻ , Br, Cl, NH ₄ ⁻	Urban		-	-	+	-	-	-	-	-	-	-	-
t3.15	Hameed et al. (2000)	SO ₄ ⁻² , NO ₃ ⁻	Urban	Mid Dec.– Early Jan.	-	-	+	-	-	-	-	-	-	-	-
t3.16	Yousufzai et al. (2000)	NO, NO _x , O ₃	Industrial		-	-	-	-	-	-	-	+	-	-	-
t3.17	Parekh et al. (2001)	TSP	Urban	Dec. 1998– Jan. 1999	+	-	-	-	-	-	-	+	-	-	-
t3.18	Ghauri et al. (2001)	Ions/metals	Mountains		-	-	-	-	-	-	-	-	-	-	+
t3.19	Barletta et al. (2002)	VOC	Urban	Winter of 98 - 99	-	-	-	-	-	-	-	+	-	-	-
t3.20	Parekh et al. (2002)	Pb in diesel and Petrol		1999	-	-	-	-	-	-	-	-	-	-	-
t3.21	Rattigan et al. (2002)	SO ₄ ⁻² , NO ₃ ⁻ , SO ₂	Urban	Dec. 1999– Jan. 2000	-	-	+	-	-	-	-	-	-	-	-
t3.22	Hashmi and Khani (2003)	SO ₂ , PM 10	Industrial	Mobile Lab	-	-	-	-	-	-	-	+	-	-	-
t3.23	Wasim et al. (2003)	TSP, Coarse, Fine	Industrial	Oct. 1998– June 1999	+	-	-	-	-	-	-	-	-	-	-
t3.24	Shah et al. (2004a)	Metals	Urban	Oct 2001 – March 2002	+	-	-	-	-	-	-	-	-	-	-
t3.25	Shah et al. (2004b)	Pb	Urban	March 2002– May, 2002	+	-	-	-	-	-	-	-	-	-	-
t3.26	Saqib and Jaffar (2004)	Pb	Urban		+	-	-	-	-	-	-	-	-	-	-
t3.27	Shaheen et al. (2005a)	TSP/Metals	Urban	June 2002– Sep.2002	+	-	-	-	-	-	-	-	-	-	-
t3.28	Shaheen et al. (2005b)	PM in 4 size fraction/Metals	Urban	Oct. 2002– May 2003	+	-	-	-	-	-	-	-	-	-	-
t3.29	Hashmi et al. (2005a)		Sea Port	7 days	-	-	-	-	-	-	-	+	-	-	-
t3.30	Hashmi et al. (2005b)	CO, NO _x , NO, O ₃ , SO ₂ ,	Urban	-	-	-	-	-	-	-	-	+	-	-	-
t3.31	Rajput et al. (2005)	TSP/ Chemical composition	Urban/ Industrial	1995 (2 weeks)	+	-	-	-	-	-	-	-	-	-	-

t3.32 **Table 3** (continued)

Authors	Pollutants	Area	Duration	Isl	Raw	Lah	Fai	Sia	Gug	She	Kar	Pes	Que	N A
t3.33 Waheed et al. (2005)	SPM/ 40 elements	Urban	-	-	-	-	+	-	+		-	-	-	-
t3.34 Waheed et al. (2006)	SPM/ 26 elements	Urban	-	-	+	+	-	-	-	-	-	-	-	-
t3.35 Qadir and Zaidi (2006)	Metals	Urban	-	-	-	+	-	-	-	-	-	-	-	-
t3.36 Ilyas (2006)	Smoke Particles	Urban	-	-	-	-	-	-	-	-	-	-	+	-
t3.37 Farhana and Husain (2006)	Metals	Urban	Dec. 2005–Jan.2006	-	-	+	-	-	-	-	-	-	-	-
t3.38 Shah et al. (2006a)	TSP/Metals	Urban	Jun. 2001–Jan. 2002	+	-	-	-	-	-	-	-	-	-	-
t3.39 Shah et al. (2006b)	PM in 4 size fraction/Metals	Urban/ Rural	Nov. 2001–Jan. 2002	+	-	-	-	-	-	-	-	-	-	-
t3.40 Husain et al. (2007b)	PM 2.5/Metals, OC,BC	Urban	Nov. 2005–Feb. 2006	-	-	+	-	-	-	-	-	-	-	-
t3.41 Shah and Shaheen (2007a)	PM in 9 size fraction/Metals	Urban	Sep. 2003–March 2004	+	-	-	-	-	-	-	-	-	-	-
t3.42 Shah and Shaheen (2007b)	TSP/Metals	Urban	May 2003–April 2004	+	-	-	-	-	-	-	-	-	-	-
t3.43 Saqib et al. (2007)	Pb	Urban	-	+	-	-	-	-	-	-	-	-	-	-
t3.44 Husain et al. (2007a)	BC,EC,OC	Urban	Dec. 2005–Jan. 2006	-	-	+	-	-	-	-	-	-	-	-
t3.45 Jafary and Faridi (2007)	TSP, CO, SO ₂ , NO ₂	Urban	-	-	-	+	-	-	-	-	-	-	-	-
t3.46 Shah and Shaheen (2008)	TSP/Metals	Urban	June 2004–May 2005	+	-	-	-	-	-	-	-	-	-	-
t3.47 Ali and Athar (2008)	CO, NO ₂ ,O ₃ , SO ₂ , TSP, Noise	Highway	-	-	-	-	-	-	-	-	-	-	-	-
t3.48 Ghauri et al. (2008)	CO, NO _x , O ₃ , SO ₂ , TSP, PM ₁₀	Urban	2003–2004	+	+	+	-	-	-	-	+	-	+	-
t3.49 Zhang et al. (2008)	PM ₁₀ , OC, EC	Urban	2006	-	-	+	-	-	-	-	-	-	-	-
t3.50 Tahir and Khan (2008)	Trace metals	Urban	March–June 2004	-	-	+	-	-	-	-	-	-	-	-
t3.51 Dutkiewicz et al. (2009)	BC	Urban	April 2006–April 07	-	-	-	-	-	-	-	+	-	-	-

Isl Islamabad, Raw Rawalpindi, Lah Lahore, Fai Faisalabad, Sia Sialkot, Gug Gujranwala, She Sheikupura, Kar Karachi, Pes Peshawar, Que Quetta, NA Northern Areas

744 **4 Air quality guidelines**

745 National Environmental Quality Standards (NEQS) were first
 746 introduced in 1993 for industrial gaseous emissions. NEQS
 747 imposed maximum limits on the concentration of the
 748 following pollutants: particulate matter, hydrogen chloride,
 749 chlorine, hydrogen fluoride, hydrogen sulfide, sulfur oxide,
 750 carbon monoxide, lead, mercury, cadmium, arsenic, copper,
 751 antimony, zinc, nitrogen, and oxides. After the establishment
 752 of NEQS, the initial response of the industrial sector to
 753 pollution control was discouraging possibly a result of

unawareness, non-availability of indigenous technology and 754
 lack of resources. For vehicle exhaust emissions, NEQS 755
 prescribed limits on smoke opacity and carbon monoxide 756
 concentration. Later, in 1999, some of the NEQS limits on the 757
 maximum allowable concentration of pollutants in gaseous 758
 emission from industrial sources were changed. The World 759
 Bank concluded that many aspects of the standards were ~~are~~ 760
 out-of-date, no longer reflecting current understanding or 761
 technologies (World Bank 2006b). Aziz (2006) reviewed the 762
 World Health Organization air quality guidelines, standards 763
 established by the Eastern Mediterranean and Southeast 764

Table 4 The concentration of different pollutants in various cities of Pakistan during 2004

		SO ₂ (µg/m ³)	NO _x (µg/m ³)	CO(mg/m ³)	O ₃ (µg/m ³)	TSP(µg/m ³)	PM ₁₀ (µg/m ³)	Pb(µg/m ³)
t4.3	Islamabad	54	45	3	35	378	189	73 ^a
t4.4	Rawalpindi	42	40	4	34	353	185	3
t4.5	Lahore	59	55	4	45	482	200	4
t4.6	Karachi	59	50	6	49	292	193	4
t4.7	Peshawar	58	49	3	47	358	219	4
t4.8	Quetta	70	59	8	48	577	251	4

These values are derived from the 48-h mean during four cycles (winter, summer, monsoon, spring) of measurements in all these cities by Ghauri et al. (2007)

^a These values were reported by Ghauri et al. (2007) and were higher by a factor of more than 10 in comparison with other reported studies carried out in Islamabad and other cities

Asian countries and proposed the guidelines for Pakistan. However, it is only recently that draft standards were announced and are awaiting approval from the Pakistan Environmental Protection Council. The draft standards are given in Table 5.

Safeguarding public health should be the main consideration for air quality standards but the proposed concentrations for PM₁₀ are considerably in excess of safe levels. The WHO guideline for PM₁₀ (annual average) is 20 µg/m³ whereas that proposed in Pakistan by 2012 is 150 µg/m³. To help improve the air quality, updated vehicle emission

standards are required. Central to air quality standards are local and national information dissemination strategies. These can raise public awareness of the issue and, in the event of high pollution levels, enable the public to take measures to prevent or alleviate health problems.

5 Conclusions

The available information on air quality in Pakistan is little and sporadic but it clearly reflects the severity of the

Table 5 Comparison of draft National Air Quality Standards for Pakistan with WHO air quality guidelines

Pollutants	Time-weighted average	Concentration in ambient air		WHO air quality guidelines ^a
		Effective from 1st January 2009	Effective from 1st January 2012	
Sulfur dioxide	Annual average ^b	80 µg/m ³	80 µg/m ³	20 µg/m ³
	24 h ^c	120 µg/m ³	120 µg/m ³	
Nitric oxide (NO)	Annual average ^b	40 µg/m ³	40 µg/m ³	40 µg/m ³
	24 h ^c	40 µg/m ³	40 µg/m ³	
Nitrogen dioxide (NO ₂)	Annual average ^b	40 µg/m ³	40 µg/m ³	40 µg/m ³
	24 h ^c	80 µg/m ³	80 µg/m ³	
Ozone (O ₃)	1 h	180 µg/m ³	130 µg/m ³	150 µg/m ³
	Annual average ^b	400 µg/m ³	360 µg/m ³	
Suspended particulate matter (SPM)	24 h ^c	550 µg/m ³	500 µg/m ³	500 µg/m ³
	Annual average ^b	200 µg/m ³	120 µg/m ³	
Particulate matter (PM ₁₀)	24 h ^c	250 µg/m ³	150 µg/m ³	20 µg/m ³
	Annual average ^b	25 µg/m ³	15 µg/m ³	50 µg/m ³
Particulate matter (PM _{2.5})	24 h ^c	40 µg/m ³	35 µg/m ³	10 µg/m ³
	Annual average ^b	25 µg/m ³	15 µg/m ³	25 µg/m ³
Lead (Pb)	1 h	25 µg/m ³	15 µg/m ³	1 µg/m ³
	Annual average ^b	2 µg/m ³	1 µg/m ³	1 µg/m ³
Carbon monoxide (CO)	24 h ^c	5 mg/m ³	5 mg/m ³	10 mg/m ³
	8 h ^c	10 mg/m ³	10 mg/m ³	30 mg/m ³

^a WHO guidelines only given if the averaging period is identical

^b Annual arithmetic mean of minimum 104 measurements in a year, taken twice a week every 24-h at uniform intervals

^c Twenty-four-hour/8-h values should be met 98% of the year. It may be exceeded 2% of the time but not on consecutive days.

784 problem. Air quality, is deteriorating with enormous speed
 785 and has been recognized as a serious problem by the
 786 Government and various other organizations. However,
 787 little work has been done in this regard. Pakistan is still
 788 unable to establish a basic air quality management capacity.
 789 There is no comprehensive air quality legislation and
 790 standards. Those studies which have been carried out
 791 reveal that the current levels of PM, SO₂, NO₂, CO, and
 792 Pb are many times higher than WHO air quality guidelines.
 793 The principal anthropogenic sources of air pollution are
 794 vehicular emissions and industrial pollution. The former is
 795 of particular concern as the number of vehicles has
 796 increased from less than one million to nearly five million
 797 within 20 years. In addition to emissions from large-scale
 798 industrial facilities, such as cement, fertilizer, steel, and
 799 power plants, numerous small- to medium-scale industries
 800 (brick kilns, steel recycling, and plastic molding) cause a
 801 disproportionate share of pollution as a result of their use of
 802 dirty 'waste' fuels (e.g., old tires, wood, and textile waste).
 803 The current state of affairs calls for urgent action to
 804 arrest the situation. Ambient air quality standards are
 805 required as a basis for emission control strategies,
 806 specifying limits for key pollutants and monitoring
 807 methods. Focus on establishing/strengthening the contin-
 808 uous air quality monitoring and implementing the basic
 809 control strategies is required. While safeguarding public
 810 health should be the main consideration, the costs and
 811 likelihood of attainment should also inform the standard-
 812 setting process. The updating of vehicle emission stand-
 813 ards along with improving the fuel quality would also
 814 help to reduce vehicular emissions. The emissions from
 815 stationary and dispersed areas combustion sources can be
 816 reduced by introduction of cleaner technologies. An
 817 integrated effort by all stakeholders holds the key to
 818 decreasing air pollution. In addition, there is a dire need
 819 to conduct scientific studies on the current levels of air
 820 pollution and their health effects in various regions of the
 821 country.

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- Q1. Waheed (2006)  Ghauri et al. (2008) were cited in the text but were not found in the reference list. Please provide the necessary information.
- Q2. Reference Pak- EPA (2007) was not cited in the text. Please provide a citation or, alternatively, delete it from the reference list 

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