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Methods: Air pollution studies in Pakistan published in both scientific journals and by the Government have been reviewed and the reported concentrations of PM, SO_2, O_3, CO, NO_2, 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. NO_2 has emerged as the second high-risk pollutant. The reported levels of PM, SO_2, CO, NO_2, and Pb were many times higher than the World Health Organization air quality guidelines. Only O_3 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.

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The state of ambient air quality in Pakistan—a review

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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.

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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.

Keywords Criteria air pollutants · Particulate matter · Pakistan

1 Background and purpose

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

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responsible for 865,000 premature deaths every year and about 60% of these deaths occur in Asia (World Health 2007). Elevated concentrations of pollutants have been found in various countries throughout Asia : India (Jain and Khare 2008; Oanh et al. 2006), Bangladesh (Begum et al. 2006), Thailand (Oanh et al. 2006; Oanh and Zhang 2004/06), Philippines (Cassidy et al. 2007; Oanh et al. 2006), Malaysia (Omar et al. 2007), Korea (Pandey et al. 2008), Vietnam (Oanh et al. 2006), Indonesia (Oanh et al. 2006), and China (Chan and Yao 2008). High levels of particulate matter ($PM_{2.5}$, PM_{10}) were reported in six Asian cities (Bandung, Bangkok, Beijing, Chennai, Manila, and Hanoi) by Oanh et al. (2006) within the framework of the Asian regional air pollution research network. The average concentrations of $PM_{2.5}$ and PM_{10} were in the range 44–168 and 54–262 $\mu g/m^3$ in the dry season, and 18–104 and 33–180 $\mu g/m^3$ in the wet season, respectively. An ongoing study by the Clean Air Initiative for Asian Cities (CAI-Asia 2006) shows that for 20 mega-cities in Asia, on average, total suspended particulate (TSP) and PM_{10} has decreased from 1993 to 2004, but ambient levels remain above the WHO guidelines. An analysis on a per city basis suggests that particulate matter is the pollutant of concern to most of the cities. Recently, Gurjar et al. (2008) evaluated the air quality of 18 mega-cities (cities of about 10 million or more inhabitants) in the world and categorized five as having ‘fair’ air quality and 13 as ‘poor’. They suggested a multi-pollutant index (MPI) which takes into account the combined level of the three World Health Organization criteria pollutants (TSP, SO_2, and NO_2). Dhaka, Beijing, Cairo, and Karachi emerged as the mega-cities with the highest MPI. Karachi, one of the mega-cities of Pakistan, appeared as the most polluted city in the world with respect to TSP and held fourth position on the MPI-based ranking. This clearly reflects the severity of air pollution in Pakistan, where very little, so far, has been done on air quality management. With approximately 35% of the population residing in towns and cities, Pakistan is the most urbanized country in South Asia.

Many Government departments and international organizations have identified degradation of ambient air quality as a major environmental concern in Pakistan. Industrial pollution, suspended particulates, indoor air pollution, and increasing traffic trends were reported as key sources affecting ambient air quality in the country (Pak-EPA 2005; Pakistan Economic Survey Report 2006–2007; World Bank 2006b; Pakistan Millennium Development Goals Report 2005). Over the last 20 years, the number of motor vehicles has risen from 0.8 million to nearly 5 million; an average growth rate in excess of 14%. The highest rise was in two-stroke vehicles (1,751%) while diesel 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 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, burning 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 operational methods. It was not until March 2007 that the

Pakistan Environment Protection Agency commenced the operation of the first Malé Declaration monitoring site in Bhawalnagar, Punjab measuring PM_{10}, TSP, SO_2, and NO_2. In March 2007, under grant in aid from the Government of Japan, continuous monitoring was instigated in Karachi, Lahore, Quetta, Peshawar, and Islamabad.

The Pakistan Economic Survey Report 2006–2007 stated that Pakistan was suffering from deterioration of air quality due to high population growth, absence of public transport and a great increase in private vehicles. The Pakistan Strategic Country Environmental Assessment World Bank Report (World Bank 2006b) identified particulate pollution as a serious environmental health concern and responsible for 22,000 premature deaths among adults and 700 deaths among children, with the total annual health burden due to PM being 1% of the gross domestic product (Table 1). In terms of annual DALYs lost, mortality accounts for an estimated 60%, followed by respiratory symptoms. This report recognized vehicular emissions, industrial pollution, and burning of municipal waste as principal sources of particulate pollution.

This review is an attempt to gather all the existing information on air quality in Pakistan and mainly concentrates on ambient air pollution studies published in both scientific journals and by the Pakistani Government. It focuses on the reported concentrations of six criteria pollutants: particulate matter, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), and lead (Pb). In addition, to emphasize the various pollution sources, details of the chemical composition of particulate matter are briefly discussed.

In Europe, North America, Latin America, Oceania, and in many Asian counties there are ambient air quality standards for air pollution. However, there are no ambient air quality standards in Pakistan. In the absence of such standards, the levels of various air pollutants have been evaluated by their comparison with the WHO (2002b, 2006) air quality guidelines. This not only gives 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 economy 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

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
Premature mortality adults	21,791	163,432
Mortality children under 5	658	22,385
Chronic bronchitis	7,825	17,215
Hospital admissions	81,312	1,301
Emergency room visits/outpatient hospital visits	1,595,080	7,178
Restricted activity days	81,541,893	24,463
Lower respiratory illness in children	4,924,148	32,007
Respiratory symptoms	706,808,732	53,011

Data from (World Bank 2006b)

Fig. 1 Political map of Pakistan

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

3 Ambient air quality measurements

3.1 Particulate matter

The first reported particulate matter measurements in Pakistan were made at a suburban residential and commercial city center site in Lahore during 1978–1980 under the Global Environment Monitoring System (GEMS). The annual mean level of suspended particulate matter (SPM) at the commercial city center was 332 μg/m^3 during 1978. At the suburban residential site, a concentration of 749 and 690 μg/m^3 was reported during the period of 1979 and 1980, respectively (WHO 1984). Later on, GEMS was extended with the inclusion of additional cities and pollutants monitored. This additional data was included in the 1992 report by the WHO/UNEP on urban air pollution in mega-cities of the world (WHO/UNEP 1992). The annual mean SPM concentration at the Space and Atmospheric Research Center in Karachi was 239 μg/m^3 in 1985 and this rose consistently during 1986, 1987, and 1988 with the valves of 265, 275, and 328 μg/m^3 respectively. In Karachi, at the Sindh Industrial Trading Estate and Sadar, the annual mean SPM concentrations during 1987 and 1988 were 254 and 459 and 333 and 397 μg/m^3, respectively. An ambient pollution survey carried out by Ghauri et al. (1992a), 1994) at 13 sites in Karachi for 15 consecutive days during May 1990 reported that the daily mean TSP concentrations were 240 ± 62 (March), 230 ± 55 (May) and 260 ± 57 μg/m^3 (June). In another study by Smith et al. (1996) for a year during 1992–1993 at three sites (city, industrial, and rural) in Lahore, the annual mean levels of TSP for the city, industrial, and rural sites were 607, 590, and 838 μg/m^3 respectively. Parekh et al. (2001) reported TSP in Karachi and Islamabad over the period of 10 December 1998 to 8 January 1999. They quote average daily TSP concentrations at Karachi in the range 627–928 μg/m^3 while those at Islamabad were between 428 and 998 μg/m^3. The average levels of PM_{10} measured by Hashmi and Khani (2003) with a mobile monitoring laboratory at the Sindh Industrial Trading Estate and Korangi Industrial Area (Karachi) were 176.5 and 147.2 μg/m^3, respectively. The hourly average PM_{10} concentration at Port Qasim in Karachi for 7 days during November was 123.49 μg/m^3 (Hashmi et al. 2005a)

In an industrial area of Islamabad from October 1998 to June 1999, Wasim et al. (2003) collected baseline data on particulate matter and reported that highest concentrations of TSP occurred in December (approximately 350 μg/m^3). In another study in Islamabad during June to September 2002, TSP was in the range of 18.5–218.6 μg/m^3 with a mean of 150.5 μg/m^3 (Shaheen et al. 2005a). An investigation carried out by Rajput et al. (2005) on TSP levels and its chemical composition in industrial and residential areas of Islamabad during 1995 depicted that the levels of TSP in the industrial area (297 μg/m^3) were more than double those of the residential area (133 μg/m^3). The Pakistan Environment Protection Agency (Pak-EPA) in collaboration with the Japan International Cooperation Agency (JICA) has carried out studies on air quality in various cities. A 2001 report (Pak-EPA/JICA 2001a) describes air quality measurements in Lahore, Rawalpindi, and Islamabad. It states that highest hourly average levels of SPM were in Lahore (895 μg/m^3) followed by Rawalpindi (709 μg/m^3) and then Islamabad (520 μg/m^3). Investigations in Gujranwala and Faisalabad showed that TSP (24 average) peaked at 5,190 μg/m^3 and 3,477 μg/m^3, respectively (Pak-EPA/JICA 2001b). A study conducted by the Environment Agency of Pakistan in Quetta reported levels of particulate matter at four different locations (two kerbside, one industrial, one residential). The concentrations of TSP, PM_{10}, and $PM_{2.5}$ varied between 385–1,778 μg/m^3, 126–709 μg/m^3 and 104–222 μg/m^3, respectively (Pak-EPA 2007). Similarly, Waheed et al. (2005, 2006) reported Q1 PM concentrations in four cities and concluded that levels of SPM in Gujranwala (53–649 µg/m^3), Faisalabad (111–435 µg/m^3), Rawalpindi (845–1,870 µg/m^3), and Lahore (1,128–1,870 µg/m^3) were exceedingly unhealthy. A similar study was conducted by Qadir and Zaidi (2006) in Faisalabad. The average mass of TSP was 550 µg/m^3 with a range of 467–600 µg/m^3.

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

Recently Ghauri et al. (2007) presented the results of a year-long baseline air quality study conducted by the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) during 2003–2004. The measurements were carried out by two mobile pollution monitoring labs at an interval of 15 min for 48 h at each site. A total of 33 sites were monitored four times (monsoon, winter, spring, summer) during the period. The survey was carried out in six major urban cities: Karachi (ten sites), Lahore (seven sites), Quetta (three sites), Rawalpindi (five sites), Islamabad (three sites), and Peshawar (five sites). With reference to TSP (1 h maximum), in Lahore, the concentration reached 996 µg/m^3 while the concentrations in other cities were still elevated: Quetta (778 µg/m^3), Peshawar (530 µg/m^3), Rawalpindi (500 µg/m^3), Islamabad (490 µg/m^3), and Karachi (410 µg/m^3). However, these cities displayed a slightly different pattern for PM_{10} (1 h maximum) with concentrations decreasing from Lahore (368 µg/m^3), Peshawar (350 µg/m^3), Quetta (331 µg/m^3), Karachi (302 µg/m^3), Islamabad (280 µg/m^3), to Rawalpindi (276 µg/m^3). The ambient air quality along the National Highway of Pakistan was monitored by Ali and Athar (2008)). The monitoring was carried out at nine sites along three sections of the highway and reported PM_{10} varied from 123 to 443 µg/m^3. Shah and Shaheen (2007b) carried out measurement of TSP (May 2003 to April 2004) and quote an average TSP concentration for Islamabad of 151.9 µg/m^3. In an investigation on TSP and heavy metals in airborne particulate matter in Islamabad Shah and Shaheen (2008) reported on the results of measurements during June 2004 to May 2005. The concentration of TSP in Islamabad varied from 41.8 to 977 µg/m^3 with a mean of 164 µg/m^3 over the year. The concentration of $PM_{2.5}$ 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 µg/m^3. Hopke et al. 2008 reported levels of $PM_{2.5}$ and PM_{10} at Nilore (Islamabad) from 2002 to 2005. The mean concentrations of $PM_{2.5}$ and PM_{10} over the 4 years were 15 and 68 µg/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 autocycles (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 µg/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

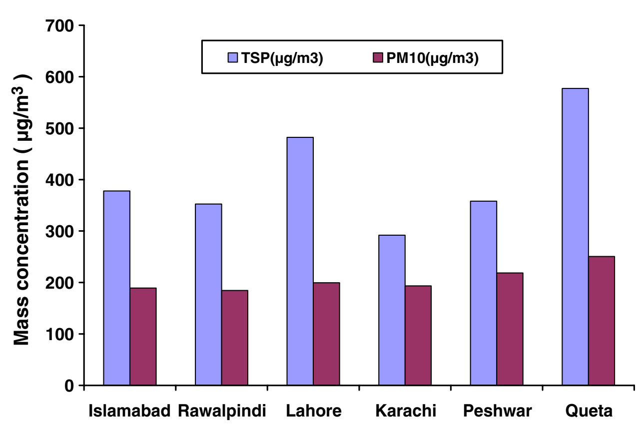

Fig. 2 Concentration of TSP and PM_{10} in different cities in Pakistan

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

City	Country	PM_{10}(μg/m^3)	Reference
Bangkok	Thailand	60	PCD (2005) Thailand
Singapore	Singapore	31	MOE&WR (2006)
Tokyo	Japan	30	BOE (2005).
Busan	South Korea	60	MOE (2006) South Korea
Seoul	South Korea	61	MOE (2006) South Korea
Daegu	South Korea	58	MOE (2006) South Korea
Incheon	South Korea	62	MOE (2006) South Korea
Jakarta	Indonesia	100	MOE (2005) Indonesia
Surabaya	Indonesia	50	ADB&CAI-Asia (2006a)
Manila	Philippines	40	ADB&CAI-Asia (2006b)
Hanoi	Vietnam	112	Khaliquzzaman (2005)
Shanghai	China	100	Fu (2004)
Beijing	China	140	BJEPB (2005)
Hong Kong	China	59	EPD (2004) China
Taipei	China	62	EPA (2007) Taiwan
Kathmandu	Nepal	129	MOEST(2005) Nepal
Colombo	Sri Lanka	80	Clean Air Sri Lanka (2006)
Dhaka	Bangladesh	131	SDNP (2007)
Kolkata	India	122	CPCD (2006)
Mumbai	India	77	CPCD (2006)
Patna	India	82	CPCD (2006)
Jodhpur	India	109	CPCD (2006)
Pune	India	137	CPCD (2006)
Ahmedabad	India	138	CPCD (2006)
Agra	India	133	CPCD (2006)
Lucknow	India	157	CPCD (2006)
Delhi	India	131	CPCD (2006)
Islamabad	Pakistan	188	World Bank (2006c)
Karachi	Pakistan	194	World Bank (2006c)
Lahore	Pakistan	202	World Bank (2006c)
Peshawar	Pakistan	202	World Bank (2006c)
Quetta	Pakistan	250	World Bank (2006c)
Rawalpindi	Pakistan	191	World Bank (2006c)

that concentrations are generally higher in Pakistani cities. Gurjar et al. (2008) quote Karachi as the most polluted city in the world with respect to TSP. According to the World Bank Development Indicator (World Bank Development Indicator 2006), by 2002, PM_{10} in Pakistan had fallen to 165 μg/m^3 from 226 μg/m^3 in 1990. These estimates were based on the Global Model of Ambient Particulates (GMAPS) and only Sudan (219 μg/m^3) and Iraq (167 μg/m^3) had higher levels than Pakistan. However, due to lack of historic continuous monitoring no consistent data sets are available to develop a clear temporal and spatial variation in PM. Based on the sporadic studies, an increasing trend in levels of PM appears more likely. GMAPS is an attempt by the World Bank to overcome the lack of monitoring information through an econometrically estimated model for predicting PM levels in world cities. It cannot replace real-time monitoring. The recent baseline study by Ghauri et al. (2007) revealed that the levels of TSP and PM_{10} in various cities were in the range of 292–577 and 189–251 μg/m^3, respectively.

3.2 Sulfur dioxide

GEMS measurements from Lahore showed that the annual SO_2 concentration, in the city center, for 1978 was 49 μg/m^3 while 40 μg/m^3 was recorded at a suburban residential area during 1979 (WHO 1984). In later studies, SO_2 was reported as 67–134 μg/m^3 in the city center as compared to 25–67 μg/m^3 at sites within the Karachi metropolitan area (WHO/UNEP 1992). These results were actually taken from the work of Ghauri et al. (1988). The bulk of the data was from a study undertaken during 12–13 June 1988. Hashmi and Khani (2003) reported that levels of SO_2 at Korangi Industrial Area and Sindh Industrial Trading Estate (Karachi) were 7.4 and 24.9 μg/m^3, respectively. At Port Qasim (Karachi) for 7 days during November, the concentration of SO_2 was 6.3 μg/m^3 (Hashmi et al. 2005a). In another study, Hashmi et al. (2005b) analyzed concentrations of SO_2 at five different stations in Karachi. Three stations were in an industrial area and one each in residential and downtown areas. Time-weighted average values were evaluated for 1 and 24 h and the maximum 24-h average of SO_2 was found at the industrial site (9.30 μg/m^3) followed by downtown (0.98 μg/m^3) and the residential area (0.24 μg/m^3).

The Pakistan Environment Protection Agency indicated that the highest concentrations of SO_2 occurred in Lahore (115 μg/m^3) followed by Rawalpindi (78.6 μg/m^3) and Islamabad (73.4 μg/m^3; Pak-EPA/JICA 2001a,b). The results of a year-long baseline air quality study conducted by SUPARCO during 2003–2004 (Ghauri et al. 2007) revealed that the concentrations of SO_2 were within the limits of the US-EPA standards. From their results, the 48-h mean concentrations of SO_2 in different cities were: Islamabad (52.4 μg/m^3), Rawalpindi (41.9 μg/m^3), Lahore (57.6 μg/m^3), Karachi (57.6 μg/m^3), Peshawar (57.6 μg/m^3), Quetta (68.1 μg/m^3). According to Ali and Athar (2008), the ambient SO_2 level over 72-h along the National Highway of Pakistan was 0.04–0.26 μg/m^3.

The main sources of SO_2 have been shown to be power-generation plants, industrial process, and diesel-fueled vehicles. Diesel vehicle numbers were three times higher in 2005 than in 1980 (World 2006a). The current levels in various cities are two to three times higher than WHO air quality guideline value (20 μg/m^3) for 24 h (WHO 2006).

3.3 Ozone

According to the GEMS study, the daily average of O_3 in Karachi was in the range 36–50 μg/m^3 (WHO/UNEP 1992). Ghauri et al. (1992b) reported measurement of O_3 during 1986–1988 at three sites (one upwind and two downwind) in Karachi. The concentration at the upwind site was 2–50 μg/m^3 and maximum levels at the downwind sites were 80 and 100 μg/m^3. In another study in Karachi (Sindh Industrial Trading Estate) Yousufzai ~~AH~~ et al. (2000) performed continuous measurements of O_3 and found the lowest level of ozone was 15 μg/m^3 rising to 38 μg/m^3 during the day. The report by Pak-EPA/JICA (2001a) showed that levels of O_3 in Lahore, Rawalpindi, and Islamabad were 17, 34, 20 μg/m^3. Within Karachi levels at Port Qasim were 24 μg/m^3 while the maximum 8 hour average at industrial area, residential and downtown areas were 19 ,13, 9.6 μg/m^3, respectively (Hashmi et al. 2005a,b). According to Ghauri et al. (2007), the 48-h mean concentration of ozone was highest in Karachi (50 μg/m^3), followed by Quetta (48 μg/m^3), Peshawar (46 μg/m^3), Lahore (44 μg/m^3), Islamabad (36 μg/m^3), and Rawalpindi (34 μg/m^3). Generally, maximum levels were found in the afternoon and peak concentrations were recorded during the summer. The current levels of O_3 in the country are well within the WHO air quality guidelines (100 μg/m^3 8-h mean). However, due to a marked rise in CNG vehicles, it is very likely that the concentration could increase substantially downwind of urban centers due to increases in vehicular NO_2 emissions.

3.4 Carbon monoxide

The first measurements of CO in Karachi were undertaken in 1969 as part of a survey at 26 road locations (Beg 1990). Concentrations were in the range 6–23 mg/m^3 near the roadside and 12–41 mg/m^3 in the center of the road during traffic congestion. In 1983, a survey from January to June showed levels of 12–23 mg/m^3; but by 1988 CO concentrations had increased and 10-h means were in the range 2–57 mg/m^3 with short-term concentrations up to 107 mg/m^3 near heavy trafficked sites. A WHO/UNEP report on urban air pollution in mega-cities of world (WHO/UNEP 1992) quoted concentrations in Karachi of 2–7 mg/m^3. However, it is worthy to note that lower levels of CO during this study are not comparable with other previous studies (e.g., Beg 1990). It is very unlikely that CO levels decreased sharply and the reported low levels could be due to differences in sampling sites. In another study in Karachi at 13 sites by Ghauri et al. (1992a, 1994) CO was in the range 10.4–11.5 mg/m^3. According to the Environmental Protection Agency (Pak- EPA/JICA 2001) the concentrations of CO in Lahore, Rawalpindi, and Islamabad were 3.2 mg/m^3, 2.1 mg/m^3, and 1.8 mg/m^3, respectively. Hashmi et al. (2005a,b) have reported CO concentrations at various sites across Karachi. The highest 8-h average CO was found in the industrial area 0.56 mg/m^3 followed by downtown 0.32 mg/m^3 and the residential site 0.14 mg/m^3. Levels were slightly higher at Port Qasim (0.71 mg/m^3; Hashmi et al. 2005a). The most recent results come from 2003–2004 by Ghauri et al. (2007). They found that Quetta had the highest concentrations (16.1 mg/m^3). In addition to the hourly average, they also calculated the 48-h mean. Again, Quetta (8.1 mg/m^3) topped the list followed by Karachi (5.8 mg/m^3), Rawalpindi, and Lahore (4.6 mg/m^3) and Islamabad and Peshawar (3.5 mg/m^3).

A large variation in CO levels have been quoted from different parts of the country, but generally higher concentrations were reported close to busy urban streets and often the US-EPA 1-hr air quality standard (40 mg/m^3) was exceeded. The WHO guidelines cover a range of averaging times: 15 min—100 mg/m^3, 30 min—60 mg/m^3, 1 h—30 mg/m^3 (WHO 2002a). Based on the available evidence, it is very likely that the currents levels would be higher during the day in urban centers in comparison to these guidelines. The increase in number of vehicles and poor mass-transit system and solid waste burning are the principal contributors to soaring levels of CO. Aziz and Bajwa (2007) calculated that inappropriate running of the mass-transit system in Lahore was responsible for 23–26% of the excess CO. Almost 48,000 tonnes of solid waste is generated each day, most of which dumped and then burnt again contributing to CO (World Bank 2006b).

3.5 Nitrogen dioxide

The data included in a 1992 report (WHO/UNEP 1992) revealed that the daily average concentration of NO_2 in Karachi was 38–544 µg/m^3. Yousufzai et al. (2000) performed continuous measurements at the Sindh Industrial Trading Estate, Karachi and quoted values for NO and NO_X in the range of 13.3–131.4 and 32.3–35.9 µg/m^3, respectively. In a 2001 report (Pak-EPA/ JICA 2001), the concentrations of NO and NO_X in Lahore, Rawalpindi, and Islamabad were 165.4, 293.3; 129.7, 139.1; and 178.6, 278.2 µg/m^3, respectively. Hashmi et al. (2005b) analyzed NO_2 concentrations within Karachi. The maximum 24-h average of NO_2 occurred at an industrial site (13 µg/m^3) while lower concentrations were recorded at residential (2.60 µg/m^3) and downtown sites (2.20 µg/m^3). More recently, Pak-EPA declared NO_2 as the second most important emerging air pollutant in Pakistan and carried out a study to assess its concentration in five major cities (Karachi, Lahore, Quetta, Peshawar, Islamabad) in 2006. Both Karachi and Lahore had an average concentration of 76 µg/m^3, followed by Quetta (69 µg/m^3), Peshawar (47 µg/m^3) and Islamabad (30 µg/m^3; Pak-EPA/JICA 2006). Another similar study was carried out at 15 different locations (schools, roads) in Murree (a mountain resort) during 18–22 September, 2006. Results indicate that the highest concentration occurred on the road side (Mall Road 76.9 µg/m^3, Ghora Gali 74.4 µg/m^3) while the minimum was recorded at the High School (5.1 µg/m^3), 1 km away from a busy road. The concentrations in Mall Road were attributed to the use of coal barbeques outside restaurants; traffic was responsible for the levels in Ghora Gali (Pak-EPA 2006). Ghauri et al. (2007) have reported that ambient concentrations of NO_X are increasing due to the introduction of CNG vehicles. The annual values derived from the 48-h mean of revealed that the current levels in the country are slightly higher than the WHO air quality guideline value of 40 µg/m^3 (Ghauri et al. 2007). Although 1-h means have not been reported concentrations must have exceeded the WHO guidelines (200 µg/m^3) as daily averages have been much larger than this figure.

3.6 Lead

Data for lead is predominantly available for Karachi and Lahore. Parekh et al. (1987) showed that mean concentration of Pb in total suspended particulate matter and water-soluble component in ambient air of Karachi was 71 µg/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 concentrations across Karachi, in decreasing order, were suburban 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 µg/m^3, industrial—1.23 µg/m^3, rural—1.21 µg/m^3.

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 µg/m^3 whereas a range of 13–90 µg/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) reported that the mean concentration at a rural site was 505 ng/m^3 (range 4–4,075 ng/m^3) compared to 185 ng/m^3 (range 16–4,000 ng/m^3) for an urban site. Shaheen et al. (2005a) evaluated levels of Pb in airborne particulate matter over Islamabad during June to September 2002. They reported a mean concentration of 146 ng/m^3 with a range of 12–481 ng/m^3. In an urban area of Islamabad, during October 2002 to May 2003 Shaheen et al. (2005b) report a mean value of 214 ng/m^3 (range 3–4,000 ng/m^3). Shah et al. (2006a) studied the distribution of Pb in TSP at 8 sites in Islamabad during June 2001 to January 2002 using high volume sampling. The mean concentration of Pb was 210 ng/m^3 (range of 37–5,979 ng/m^3). An investigation on the spatial variation of metals and particle size distribution in TSP at a rural and urban site around Islamabad during November 2002–April 2003 was carried out by Shah et al. (2006b). This study revealed higher concentrations at the rural site (320 ng/m^3) compared to the urban one (160 ng/m^3). It was argued that rural site was close to a main road and, moreover, was downwind of the city center which lead to the heavy burden of Pb. The results of Shah and Shaheen (2007a) showed that during September 2003–March 2004 the mean concentration of Pb in Islamabad was 128 ng/m^3 with a range of 13–360 ng/m^3.

Shah and Shaheen (2007b) quoted an average of 182 ng/m^3 (range of 2–895 ng/m^3) during May 2003–April 2004 in Islamabad. In another investigation on TSP and heavy metals in airborne particulate matter during June 2004–May 2005, in Islamabad, Shah and Shaheen (2008) showed that Pb ranged from 5–895 ng/m^3 with a mean of 144 ng/m^3. Saqib et al. (2007) extended their earlier work (Saqib and Jaffar 2004) on lead to Rawalpindi. Here, high volume sampling yielded values between 22 and 57 μg/m^3 while dithizone-carbon tetrachloride scrubbing indicated levels of 18 to 39 μg/m^3. Again, these concentrations are significantly higher than those reported by other workers. The atmospheric chemistry of Lahore was explored by Farhana and Husain (2006) during December 2005–January 2006 and reported levels of Pb were 12 μg/m^3. In a study conducted by Qadir and Zaidi (2006) in Faisalabad, the reported levels of Pb were 549 ng/m^3. Ghauri et al. (2007) year-long baseline air quality study during 2003–2004 revealed a very high concentration of Pb in Islamabad as compared to other cities of Pakistan. The reported mean 48-h concentration in Islamabad was 73 μg/m^3—not to dissimilar to the results of Saqib and Jaffar (2004). The mean 48-h levels in Lahore, Karachi, Peshawar, and Quetta were in the range of 2–5 μg/m^3. The recent surveys in the country suggest that there has been a decrease in concentration of Pb in ambient air since the removal of lead from petrol in 2002. However, despite the variability in documented concentrations the current levels are still many times higher than WHO (2002a) of 500 ng/m^3 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, SO_4^{-2}, NO_3^-, Br, Cl, and NH_4^-) were determined as well. Based on metallic and ionic composition emissions from oil and coal combustion, industrial processes, building construction 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 concentrations 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 Islamabad. These sites measure particulate matter, hydrocarbons, O_3, CO, SO_2 and NO_2.

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

	Authors	Pollutants	Area	Duration	Isl	Raw	Lah	Fai	Sia	Gug	She	Kar	Pes	Que	NA
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)	PAH~~C~~ – 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	NA
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												
Q1 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, *Guj* Gujranwala, *She* Sheikupura, *Kar* Karachi, *Pes* Peshawar, *Que* Quetta, *NA* Northern Areas

4 Air quality guidelines

National Environmental Quality Standards (NEQS) were first introduced in 1993 for industrial gaseous emissions. NEQS imposed maximum limits on the concentration of the following pollutants: particulate matter, hydrogen chloride, chlorine, hydrogen fluoride, hydrogen sulfide, sulfur oxide, carbon monoxide, lead, mercury, cadmium, arsenic, copper, antimony, zinc, nitrogen, and oxides. After the establishment of NEQS, the initial response of the industrial sector to pollution control was discouraging possibly a result of unawareness, non-availability of indigenous technology and lack of resources. For vehicle exhaust emissions, NEQS prescribed limits on smoke opacity and carbon monoxide concentration. Later, in 1999, some of the NEQS limits on the maximum allowable concentration of pollutants in gaseous emission from industrial sources were changed. The World Bank concluded that many aspects of the standards were are out-of-date, no longer reflecting current understanding or technologies (World Bank 2006b). Aziz (2006) reviewed the World Health Organization air quality guidelines, standards established by the Eastern Mediterranean and Southeast

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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)
Islamabad	54	45	3	35	378	189	73[a]
Rawalpindi	42	40	4	34	353	185	3
Lahore	59	55	4	45	482	200	4
Karachi	59	50	6	49	292	193	4
Peshawar	58	49	3	47	358	219	4
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 PM_{10} are considerably in excess of safe levels. The WHO guideline for PM_{10} (annual average) is 20 µg/m^3 whereas that proposed in Pakistan by 2012 is 150 µg/m^3. 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	
	24 h[c]	120 µg/m^3	120 µg/m^3	20 µg/m^3
Nitric oxide (NO)	Annual average[b]	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	
Suspended particulate matter (SPM)	Annual average[b]	400 µg/m^3	360 µg/m^3	
	24 h[c]	550 µg/m^3	500 µg/m^3	
Particulate matter (PM_{10})	Annual average[b]	200 µg/m^3	120 µg/m^3	20 µg/m^3
	24 h[c]	250 µg/m^3	150 µg/m^3	50 µg/m^3
Particulate matter ($PM_{2.5}$)	Annual average[b]	25 µg/m^3	15 µg/m^3	10 µg/m^3
	24 h[c]	40 µg/m^3	35 µg/m^3	25 µg/m^3
	1 h	25 µg/m^3	15 µg/m^3	1 µg/m^3
Lead (Pb)	Annual average[b]	[illegible]/m^3	1 µg/m^3	[illegible]g/m^3
	24 h[c]	2 µg/m^3	[illegible]g/m^3	
Carbon monoxide (CO)	8 h[c]	5 mg/m^3	5 mg/m^3	10 mg/m^3
	1 h	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.

problem. Air quality, is deteriorating with enormous speed and has been recognized as a serious problem by the Government and various other organizations. However, little work has been done in this regard. Pakistan is still unable to establish a basic air quality management capacity. There is no comprehensive air quality legislation and standards. Those studies which have been carried out reveal that the current levels of PM, SO_2, NO_2, CO, and Pb are many times higher than WHO air quality guidelines. The principal anthropogenic sources of air pollution are vehicular emissions and industrial pollution. The former is of particular concern as the number of vehicles has increased from less than one million to nearly five million within 20 years. In addition to emissions from large-scale industrial facilities, such as cement, fertilizer, steel, and power plants, numerous small- to medium-scale industries (brick kilns, steel recycling, and plastic molding) cause a disproportionate share of pollution as a result of their use of dirty 'waste' fuels (e.g., old tires, wood, and textile waste).

The current state of affairs calls for urgent action to arrest the situation. Ambient air quality standards are required as a basis for emission control strategies, specifying limits for key pollutants and monitoring methods. Focus on establishing/strengthening the continuous air quality monitoring and implementing the basic control strategies is required. While safeguarding public health should be the main consideration, the costs and likelihood of attainment should also inform the standard-setting process. The updating of vehicle emission standards along with improving the fuel quality would also help to reduce vehicular emissions. The emissions from stationary and dispersed areas combustion sources can be reduced by introduction of cleaner technologies. An integrated effort by all stakeholders holds the key to decreasing air pollution. In addition, there is a dire need to conduct scientific studies on the current levels of air pollution and their health effects in various regions of the country.

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Q1. Waheed (2006) and 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.