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Critical Literature Review

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Urban air quality management–A review

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ABSTRACT

Urban air quality management plan (UAQMP) is an effective and efficient tool employed in managing acceptable urban air quality. However, the UAQM practices are specific to a country's needs and requirements. Majority of the developed countries have full–fledged UAQMP with a regulatory management framework. However, developing countries are still working in formulating the effective and efficient UAQMPs to manage their deteriorating urban air environment. The first step in the process of formulation of UAQMP is to identify the air quality control regions based on ambient air quality status and second, initiate a time bound program involving all stakeholders to develop UAQMPs. The successful implementation of UAQMPs depends on the strength of its key components, e.g. goal/objective, monitoring network, emission inventory, air quality modeling, control strategies and public participation. This paper presents a comprehensive review on UAQMPs, being implemented worldwide at different scales e.g., national (macro), city (medium), and local (micro).

Keywords: *Urban air quality management plan, urban hot spot, vehicular air pollution, air quality monitoring and modeling, urban air pollution control*

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1. Introduction

Urban air pollution (UAP) is a major concern throughout the world in both, developed and developing countries. Swelling urban population and increased volume of motorized traffic in cities have resulted in severe air pollution affecting the surrounding environment and human health. The World Health Organization (WHO) has estimated that in developing countries, increasing UAP has resulted in more than 2 million deaths per annum along with various cases of respiratory illnesses (WHO, 2005; Cities Alliance, 2007; WHO, 2014). One of the major sources of UAP is the road transport sector. Besides, domestic, commercial and industrial activities also contribute to UAP. It is reported that over 70–80% of air pollution in mega cities in developing nations is attributed to vehicular emissions caused by a large number of older vehicles coupled with poor vehicle maintenance, inadequate road infrastructure and low fuel quality (Auto Fuel Policy, 2002; Molina and Molina, 2002; Badami, 2005; Anjaneyulu et al., 2006; Molina et al., 2007; Singh et al., 2007; Wang et al., 2010). The criteria pollutants responsible for deteriorating urban air quality are oxides of nitrogen (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM) and volatile organic compounds (VOCs). Re–suspension of road dust due to movement of traffic and tyre and brake wear are also some of the significant sources of ambient PM concentrations in urban areas (Amato et al., 2014). Ambient air pollutant concentrations are distributed non–uniformly in urban areas, creating hot spots mostly in central business district, traffic intersections and signalized roadways (Kandlikar, 2007). Besides, topographical and meteorological variations in urban areas lead to complex spatial and temporal variations in pollutant concentrations (Gokhale and Khare, 2007). The spatial scale of UAQMP varies from macro (national level) to medium (city level) and micro level (site specific). The temporal scale is either long–term or short term, based on the national ambient air quality standard (NAAQS). Further, Table 1 describes the UAQM definitions/concepts (Laxen, 1993; Longhurst et al., 1996; Steinar et al., 1997; Fedra and Haurie, 1999; Beattie et al., 2001; Karatzas, 2002; Gokhale and Khare, 2007; Vlachokostas et al., 2009; Sivertsen and Bartonova, 2012). In addition, Woodfield et al. (2006) have evaluated regional groupings among local authorities to manage urban air quality in London, the West Midlands and former–Avon area of Southwest England. They have reported variations in methods and tools used in developing the local air quality management plan. Further, Longhurst et al. (2009) have discussed the challenges in the source–control approach of air quality management and recommended the development of an integrated, risk management effect–based process of urban air quality management. They have also reported the importance of periodically evaluating the dynamic nature of management challenges by reviewing components of UAQM protocol. In the recent past, Figueiredo et al. (2013) have carried out an assessment of source contribution to urban air quality in the city of Estarreja in Portugal and observed that O_3 and PM_{10} concentrations exceeded urban air quality standards. As a result, the authors have suggested strategies to reduce O_3 and PM_{10} concentrations from motorized road transport and industrial activities. A majority of the existing UAQMPs have been developed both at macro (national) or medium (city) levels and for long–term duration considering the average ambient pollutant concentrations (Steinar et al., 1997; NRC, 2004; CPCB, 2006; NILU, 2007; DEAT, 2008). Gokhale and Khare (2007) have introduced the concept of an e– UAQMP framework to forecast the air pollution episodes at a selected urban air quality control region and further suggested mitigation plans. This paper is an attempt to present a comprehensive review on UAQMPs that assist regulatory authorities in maintaining the acceptable urban air quality.

2. Urban Air Pollution in Mega Cities

In developed countries, trends of urbanization and the associated growth of cities have started to reverse due to severe levels of congestion (Mayer, 1999). However, in developing countries, city's growth tends to be from periphery to core. The ambient air pollution levels at urban hot spots in 20 European cities have exceeded the urban background concentrations due to increase in traffic volume (Moussiopoulos et al., 2005). In the UK, motorized road transport has been categorized as one of the largest single pollution sources in 92% of declared air quality management areas (AQMAs) which accounts for 33% emissions of NO_X and 21% of PM_{10}, and so, frequently violating the national ambient air quality standards/objectives (Faulkner and Russell, 2010). However, in the recent past, it has been observed that in some mega cities of developed countries, urban air quality is showing signs of improvement on account of efficient implementation of UAQMP (NSW Government, 2010; EEA, 2011a; Parrish et al., 2011; EEA, 2013a). In the European Environment Agency (EEA) countries, the emission reduction from vehicular exhausts from 1990 to 2009 has been reported to be around 54% for SO_2, 27% for NO_X, 16% for PM_{10} and 21% for $PM_{2.5}$. In spite of all these efforts in place, it has been observed that 18% to 49% of the population in these countries is still exposed to PM_{10} concentrations exceeding the ambient standards (EEA, 2011a). In North American megacities like, Los Angeles, New York, and Mexico City, the ambient air quality concentrations for some criteria pollutants have shown declining trends during the last five decades, particularly the O_3 concentrations. In the year 2010, 8–hour average ambient O_3 concentrations have been observed to be 17% lower compared to the concentrations in the year 1990. Similarly, 24–hour average PM_{10} concentrations have been found to be 38% lower in 2010 when compared with levels in 1990; and so with NO_2 and SO_2 concentrations which have been reported to be 45% and 17% lower in 2010 when compared with 1990 concentration levels, respectively. However, at some designated non–attainment areas NAAQS is still violated (Parrish et al., 2011; U.S. EPA, 2012). In New South Wales (NSW) in Australia, road transport is the single largest source of NO_X emissions that contributes more than 71% of total emissions. One–hourly average NO_2 concentrations have shown a declining trend from 1980 to 2009. However, the annual average concentration trend of $PM_{2.5}$ has remained more or less constant from 1997 to 2009. The reduction in ambient NO_2 concentrations during this period may be due to the implementation of UAQMP maintaining cleaner fuel standards (NSW Government, 2010). The cited examples clearly show definite benefits of the UAQMPs.

In the Asian subcontinent, some developed countries, e.g. Singapore, Japan and Hong Kong, are facing street–level air pollution problems due to an increase in the number of motorized transport (ADB, 2006a; CEC, 2011; Edesess, 2011). In developing countries, mega cities are facing acute problems due to an increase in the ambient PM and NO_2 concentrations as a result of rapid urbanization. In Shanghai, New Delhi, Mumbai, Guangzhou, Chongqing, Calcutta, Beijing, and Bangkok the ambient PM and NO_2 concentrations frequently violate WHO guidelines (Baldasano et al., 2003). Poor fuel quality, high traffic density, large proportion of old vehicles, poor road infrastructure and inadequate inspection and maintenance (I/M) programs, are some of the major causes of deteriorating urban air quality (Gurjar et al., 2004; Badami, 2005). Chan and Yao (2008) have reported that ambient concentrations of PM_{10} and SO_2 in the Chinese cities of Shanghai and Pearl River Delta are four to six times higher than concentrations observed in any of the cities in developed countries. In Beijing, the annual average NO_2 concentrations remain constant at a level of 70 $\mu g/m^3$ ±10%. However, 90% of the time, PM concentrations exceed the NAAQS and WHO–AQG (Zheng et al., 2005; Duan et al., 2006). One of the studies carried out recently has found that the annual average PM_{10} concentrations in Asian cities are four times higher than WHO–AQG of 20 $\mu g/m^3$ (Atash, 2007; CAI–Asia, 2010a; UN–Habitat, 2010). In the Indian metropolitan cities (Delhi, Mumbai, Kolkata and Chennai), ambient PM concentrations frequently violate NAAQS as well as WHO guidelines (Gupta and Kumar, 2006; Singh et al., 2007; CPCB, 2010a; Gupta et al., 2010). Mohan and Kandya (2007) have analyzed nine years of data at seven different locations in the city of Delhi and reported that at one of the locations (ITO intersection), the air quality has been found to be "worst". In South Africa, the air quality act, 2004 contains specific provisions to deal urban hot spot by declaring it as the "priority area" (DEAT, 2008). Gurjar et al. (2008) have developed a multi–pollutant index for 18 megacities of the world, out of which, five are classified as ''fair'' and thirteen as ''poor''. Further, Ramachandra and Shwetmala (2009) have reported that India's transport sector emits 258.10 Tg of CO_2, of which 94.5% is contributed by motorized road transport. The Central Pollution Control Board (CPCB) has reported that vehicular contribution to the total urban air pollution

Table 1. *The UAQM definition/concept*

References	Air quality management definition/concept
Laxen (1993)	AQMP is a program to ensure the control of emissions to protect public health and welfare.
Longhurst et al. (1996)	Concept of the local air quality management plan (LAQMP) emphasizes the distribution of power at community level and strong communication and cooperation between actors of air quality management.
Steinar et al. (1997)	AQMP is a system for design and implementation of monitoring, management and policies within an urban area.
Fedra and Haurie (1999)	A system that can establish a robust and integrated environmental management life cycle for urban areas of interest.
Beattie et al. (2001)	The UAQM emphasizes on local action to deal urban hot spots of air pollution (episode).
Karatzas (2002)	A software tools that combine air quality models with other software modules like geographical information systems, databases, expert systems and statistical analysis tools. It helps to interpret the complex interactions between various atmospheric, emission, land use and topographic parameters.
Woodfield et al. (2003)	The UAQM identifies specific pollution hot spots based on advanced and complex air–quality dispersion modeling and monitoring techniques.
Gokhale and Khare (2007)	Episodic urban air quality management plan (e–UAQMP)–it uses hybrid model to forecast extreme levels of pollutants during peak traffic hours.
Vlachokostas et al. (2009)	AQMP is an integrated assessment methodological scheme for the evaluation of air pollution control measures that are put forward in order to reduce air pollution levels in urban areas. This approach brings together air quality modeling and mathematical programming techniques, provides a decision support system for the determination of optimal bundles of air pollution control options according to the particular features and needs of the areas examined.
Sivertsen and Bartonova (2012)	The UAQM is a set of action that helps in attaining air quality goals in a specified geographical area. It requires actions by government, business, industry, NGO's and the population.

in Delhi and Mumbai is about 76–90% for CO, 66–74% for NO_X, 5–12% for SO_2 and 3–12% for PM (CPCB, 2010a). Recently, studies carried out by Yale University, USA, and WHO, have ranked Delhi as the "worst" polluted city based on environment performance index (TOI, 2014; The Hindu, 2014). Therefore, necessary mitigation measures need to be implemented through effective and efficient implementation of UAQMP to maintain an acceptable urban air quality.

3. Urban Air Quality Management

The UAQM practices are country specific and based on the priorities as agreed for a specific air quality control region to maintain an acceptable ambient air quality. They are implemented and enforced through legislative laws (Elsom, 1996; Longhurst et al., 1996). Table 2 describes and compares various legislative laws and regulations dealing with UAQM which have been implemented in selected developed and developing countries of the world. The key components of UAQMP are air quality objectives, monitoring, emission inventory, prediction and forecasting tools, control strategies and public participation. Further, each component plays a significant role in improving the efficiency of the UAQMP, thus reducing pollutant concentrations. Moreover, the effective and efficient implementation of UAQMP in developing countries still remains a challenging task for air quality managers due to lack of government commitment and stakeholder participation, weaknesses in policies, standards and regulations, lack of real–time air quality data and emission inventories (KEI, 2002; ADB, 2006b; Naiker et al., 2012). In one of the studies carried out in Indonesia, Santosa et al. (2008) have reported that urban air pollution is perhaps the most severe environmental problem due to rapid growth in industrial and transportation sectors. The management practices to improve urban air quality are very limited and the portion of the budget allocated for urban air quality management is also insufficient. In the recent past, Kura et al. (2013) have analyzed urban air pollution problems in China, India and Brazil at a macro urban scale and proposed a system based methodology to develop the UAQMP that takes into account (i) identification of critical pollutants and their sources, (ii) setting up of the air quality monitoring network, (iii) emission inventory, (iv) source prioritization, (v) control strategies, and (vi) development of decision support system. Key components of the existing UAQMP have been critically reviewed and discussed in the following sections.

3.1. Air quality objectives/standards

Air quality objectives/standards are principal components of any UAQMP that act as a prerequisite to clear policies and goals. The formulation of the objectives/standards requires comprehensive discussions and reviews with stakeholders at various levels of hierarchy e.g. national, regional and local (Longhurst et al., 1996). In USA, air quality standards are categorized for ambient and hazardous pollutants. The ambient standards are described under NAAQS consisting of criteria pollutants such as O_3, CO, SO_2, NO_2, and PM (U.S. EPA, 2011a). In the UK, the ambient air quality standards are based on the carrying capacity of the environment. However, the UAQM policies specify a target timeline within which the controlling authorities have to achieve the objectives/standards. The EU's air quality directive contains limit and target values (DEFRA, 2011a).

In the developing world, most of the countries have evolved their own air quality standards. However, some countries follow the WHO–AQG and specify them as their standards (WHO, 2005). The WHO–AQG for PM is stringent than any other ambient air quality standards specified in USA, UK and EU countries. In South Africa, the air quality objectives and standards are formulated involving stakeholders and community goals and priorities (DEAT, 2008). In India and China, the NAAQS has been formulated based on land use type i.e. sensitive, residential/commercial and industrial (MoEF, 2009; MEP, 2013). NAAQS in India has been set up for 13 pollutants (MoEF, 2009). Table 3 describes air quality standards/objectives followed in different countries of the world including the WHO–AQG.

3.2. Air quality monitoring

Air quality monitoring provides information regarding the status of present air quality. It helps in evaluating the existing policies and their effective implementation. One of the important components of any air quality monitoring program is planning, design and establishment of monitoring network based on the air quality objectives (Sivertsen, 2008). Graves et al. (1981) have designed a monitoring network in Fulton County, Georgia, in which only non–reactive pollutants are monitored in ambient air. Air quality monitoring network in Greater London area has been designed specifically with an objective to carry out spatial correlation analysis using the data obtained from the monitoring stations (Handscombe and Elsom, 1982). Mofarrah and Husain (2010) have used multiple–criteria approach in designing an optimal air quality–monitoring network in Riyadh City, Saudi Arabia. Table 4 describes various air quality–monitoring networks being used in different countries.

In USA, the monitoring network is designed and operated following common guidelines of Office of Air Quality Planning and Standards. Monitoring network data are analyzed to forecast air quality index (AQI) in over 300 cities (AIRNow, 2011). In UK, over 300 air quality–monitoring stations are operated (DEFRA, 2013). Real time hourly average air quality information is available through electronic media and web platforms. The EU countries administer their monitoring network through European Topic Centre on Air Pollution and Climate Change (EEA, 2014).

In most of the developing countries, the air quality–monitoring network has been designed primarily to ensure effective regulatory compliance. In South Africa, 94 air quality–monitoring stations are operated throughout the country ensuring regulatory compliance (DEA, 2011). In China, the CNEMC is responsible for operation and maintenance of air quality monitoring stations in 113 cities with more than 2 000 stations (Shasha, 2010). In Hong Kong, 14 online continuous monitoring stations are in operation and maintained by Environment Protection Department (EPD, 2011). However, the Pearl River Delta regional air quality monitoring network serves as a role model for cooperation between the two governments and among various local authorities to address the air pollution problems in a more effective and holistic manner (Zhong et al., 2013a). In India, national ambient air quality monitoring (NAAQM) network is having 342 monitoring stations in 127 cities/towns in 26 states and 4 union territories. Additionally, individual state pollution control boards are operating their own monitoring stations (CPCB, 2014). In the recent past, the Ministry of Earth Sciences, Government of India has started monitoring of criteria air pollutants, specifically designed for Delhi City and operated by the Indian Institute of Tropical Meteorology (IITM), Pune (IITM, 2014).

3.3. Source apportionment

Source apportionment (SA) studies are conducted to identify and quantify the impact of different sources of air pollutants at receptor sites. An efficient and effective UAQMP needs input on categories of sources that may contribute to ambient air pollution followed by their quantification. Based on this information, effective UAQM strategies can be formulated and implemented. The SA studies can be performed using methods that rely on an analysis of morphological and chemical composition of pollutants. The latter, being the quantitative technique, is preferred over the former one for use in large–scale studies. Chemical characterization, thus, is an important step in the SA studies that focuses on obtaining chemical constituents of the PM, which depend on

Table 2. *Urban air quality management system/process*

Country	Air Quality Management Process	Scale	Designated Area	References
USA	The management practices were introduced in the Clean Air Act (CAA), 1963 and Air Quality Act (AQA), 1967. The CAA, 1963 recommends a set of responsibilities and relationships among federal, state, tribal, and local agencies regarding air quality management. The USEPA and states have designated the non–attainment areas (NAAs) that experience *unhealthy* levels due to exceedences of *criteria* pollutants. The local governments have developed rules/guidelines (State Implementation Plan, SIP) to reduce the pollution level in order to comply with (or attain) the specified standard.	Local and district level	NAAs	NRC (2004); Green and Cummins (2007)
Europe	The air quality management practices were introduced in 1980 with directive 80/779/EEC. In UK, the LAQM technical guidelines support local authorities in carrying out their duties under the Environment Act 1995 and the Environment (Northern Ireland) Order 2002 which further revised and improved in 2000, 2003 and 2009 with participation of stakeholders.	Area specific e.g. urban *hot spot*	AQMA	Longhurst et al. (1996); DEFRA (1998); DEFRA (2009a); DEFRA (2009b)
Australia	Urban air quality is managed through the national plan instead of region–specific plan of Environment Protection and Biodiversity Conservation Act, 1999. City councils have their own UAQMPs with more emphasis on emission reduction from transport sector.	National/city scales	AQMA	EPA (2007); Commonwealth of Australia (2011); AQCC (2012)
British Columbia	The UAQMP is implemented through Clean Air Provisions of Environmental Management Act, 2004. The air pollution management is applied successfully as airshed action strategies.	Local scale (airshed)		Williams and Bhattacharyya (2004); B.C. Government (2008)
Mexico	UAQM practices are implemented first time in 1999 to reduce the criteria pollutant concentrations in urban areas. The ministry of environment and natural resources is the regulatory body to implement the UAQM strategies throughout Mexico.	City scale	NAAs	Molina and Molina (2002)
South Africa	The National Environmental Management–Air Quality Act, 2004 introduced the UAQMP. This act implemented air quality standards in South Africa. The primary aim is decentralization of the implementing agencies.	City scale	Priorities area	DEAT (2008); Naiker et al. (2012)
China	The UAQM starts with 2nd revision in Air Pollution Prevention and Control Act in 2000. Recently, the state council has introduced action plans to control the urban air pollution at city as well as local scales.	City/local scale		Chan and Yao (2008); Wang and Hao (2012); CAAC (2013); MEP (2013)
India	The UAQM practices initiated after implementation of the Air (Prevention and Control of Pollution) Act, 1981. At present, no UAQMP exists to manage urban air pollution in Indian cities. The CPCB has issued guidelines to prepare action plans for sixteen polluted cities.	City scale	NAAs	CPCB (2006)

Table 3. *Comparative analysis of NAAQS for criteria pollutants*

Pollutants	Developed Countries				Developing Countries							International
	UK/EU 2005 [a]	US [b]	Australia [c]	British Columbia [d]	South Africa [e]	Mexico [f]	China I [g]	China II [g]	China III [g]	India I [h]	India II [h]	WHO [i]
SO_2 (μg/m^3)												
1 hr	350, 24/year [j]		200	900	350, 88/year		150	500	700			
24 hr	125, 3/year	365, 1/year	80	260	120, 4/year	0.13 ppm 1/year	50	150	250	80	80	125
Annual	20		20	50	50	0.03 ppm	20	60	100	50	20	50
NO_2 (μg/m^3)												
1 hr	200, 18/year, (EU 2010)		120	400	200, 88/year	0.21ppm, 1/year	120	120	240			200
24 hr				200			80	80	120	80	80	
Annual	40 (EU, 2010)	100	30	60	40		40	40	80	40	30	40
PM_{10} (μg/m^3)												
24 hr	50, 35/year	150, 1/year	50	50	120, 4/year	120	50	150	250	100	100	50
Annual	40	50			50	50	40	100	150	60	60	20
$PM_{2.5}$ (μg/m^3)												
24 hr		35, 98%	25	25		65	50	150	250	60	60	25
Annual	25	15	8	8		15	40	100	150	40	40	10
CO (μg/m^3)												
1 hr		40 000, 1/year		28 000	30 000, 88/year		10 000	10 000	10 000	4 000	4 000	30 000
8 hr	10 000	10 000, 1/year	9 000	11 000	10 000, 11/year	11 ppm 1/year				2 000	2 000	10 000
24 hr							4 000	4 000	4 000			

[a] *Source: http://uk-air.defra.gov.uk/documents/National_air_quality_objectives.pdf*
[b] *Source: http://www.epa.gov/air/criteria.html*
[c] *Source: http://www.environment.gov.au/topics/environment-protection/air-quality/air-quality-standards#air*
[d] *http://www.bcairquality.ca/reports/pdfs/aqotable.pdf*
[e] *DEA (2009)*
[f] *http://transportpolicy.net/index.php?title=Mexico:_Air_Quality_Standards (PM_{10} and $PM_{2.5}$ value should be met at 98% of the time in a year)*
[g] *China: Zone I: Residential areas; Zone II: Commercial areas; Zone III: Industrial areas (http://www.vecc-sepa.org.cn/eng/news/news_detail.jsp?newsid=e00397)*
[h] *India I -Industrial, Residential, Rural and other area, India II -Ecological sensitive area, 98 % of the time in year*
[i] *WHO-AQG (WHO, 2005)*
[j] *24 per year means 24 exceedances per year are permitted*

Table 4. *Air quality monitoring networks*

Countries	Air Quality Monitoring Network	Automatic/Manual	Pollutants Monitored	Available Online
US	(i) State and local air monitoring stations (SLAMS), (ii) National air monitoring stations (NAMS) (iii) Special purpose monitor station (SPMS) for very specific or short–term monitoring goals and (iv) Photochemical assessment monitoring station (PAMS).	Both	CO, Pb, NO_2, O_3, PM, SO_2	www.airnow.gov
UK	Categorized based on land use type: Urban (U), Suburban (S), Rural (R), Traffic (T), Industrial (I) and Background (B). Automatic Rural and Urban Network (ARUN) is the largest monitoring network.	Both	NO_X, SO_2, O_3, CO and PM (PM_{10} and $PM_{2.5}$)	www.uk–air.defra.gov.uk/network
EU	Categorized based on compliance, exposure assessment, on–line monitoring (episode), and operational monitoring (adjacent to specific source).	Both	NO_X, NO_2 SO_2, O_3, CO, PM (PM_{10} and $PM_{2.5}$), Benzene	www.eea.europa.eu/data–and–maps/data/airbase
Australia	Urban and Regional based on population >25000. Monitoring is not done if previous measurements or screening studies have shown that specific pollutant levels would be consistently below the NAAQS.	Both	CO, NO_2, O_3, SO_2, PM_{10} and $PM_{2.5}$	www.environment.nsw.gov.au/aqms
British Columbia	Continuous (hourly), non–continuous (24 hourly) and mobile (episodic).	Both	CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2	www.envistaweb.env.gov.bc.ca
Mexico	Manual monitoring stations started in 1972. Automatic air–quality monitoring network established in late 1980s. Air quality data are shared through National Information System.	Both	O_3, NO_2, SO_2, PM_{10}, $PM_{2.5}$, CO	http://sinaica2.inecc.gob.mx/magic/rmart
South Africa	The South Africa Air Quality Information System (SAAQIS).	Manual	CO, NO_2, PM_{10}, SO_2	www.saaqis.org.za
China	The Chinese National Environmental Monitoring Center (CNEMC).	Both	CO, SO_2, O_3, NO_2 and PM_{10} and $PM_{2.5}$	www.aqicn.org
India	National Ambient Air Quality Programme (NAAQM).	Both	SO_2, NO_X, SPM, CO and PM_{10}	http://164.100.43.188/cpcbnew

sources and their emission rates. To apportion the sources, receptor models are used, which quantify pollutant concentrations based on the measured ambient air pollutant data. SA studies using receptor models date back to late 1960's, with the first study reported in literature by Blifford and Meeker (1967). They have examined particle composition data of SPM collected by the National Air Sampling Network (NASN) during 1957–61 in 30 U.S. cities using factor analysis and eigenvector method for 13 elements. Very few studies have been conducted nation–wide (Thurston et al., 1984; CPCB, 2010a; Thurston et al., 2011); majority of the studies have been conducted only on regional and local scales (Ito et al., 2004; Qin et al., 2006; Tao et al., 2013; Li et al., 2014). However, the focus of these studies has been shifting from coarser particles (SPM, PM_{10}) to finer particles ($PM_{2.5}$, PM_1) that significantly affect health (Schauer and Cass, 2000; Mazzera et al., 2001; Chakrobarty and Gupta, 2010; Khare and Baruah, 2010; Pandolfi et al., 2011). One of the important parameters in SA studies is the selection of marker species or source profiles. Metals have been used invariably as marker species for identification of sources–for instance, Al, Si, Ti, Ca for crustal/soil sources; Ni, V for residual/fuel oil combustion; Zn, Cr for refuse burning/incineration; and Zn, Cr, Pb, Cu for vehicular emissions (Watson et al., 2001; Chow et al., 2011; Patil et al., 2013). The ratio between two metal concentrations represents the characteristic of a particular source which is an important input for receptor models. Besides, an efficient and effective UAQMP requires specific information on emission sources which may be categorized based on the type of fuel used. In order to identify such sources, organic molecular markers are used as tracers along with metals, ions and EC/OC (Schauer et al., 1996; Perrone et al., 2012; Li et al., 2014). These markers have a high degree of source specificity; for instance, levoglucosan from cellulose has been used as a specific marker compound for wood burning; hopane and stearanes for mobile source emissions; and polycyclic aromatic hydrocarbon (PAH) profiles for distinguishing between gasoline and diesel vehicle emissions (Simoneit et al., 1999; Sharma et al., 2003; Chowdhury et al., 2007; Lin et al., 2010; Masih et al., 2010; Herlekar et al., 2012). Hasheminassab et al. (2013) have used molecular marker–based chemical mass balance model (MM–CMB), which possesses higher source identification efficiency when compared to CMB, which is one of the most widely used receptor models (Watson et al., 2002; Watson et al., 2008). Other receptor modeling techniques used in SA studies include enrichment factor analysis, times series analysis, multivariate factor analysis (principal component analysis and positive matrix factorization), UNMIX, species series analysis and multi–linear engine (ME) analysis (Cooper and Watson, 1980; Henry et al., 1984; Hopke, 1991; Ramadan et al., 2003; Almeida et al., 2006; Hwang et al., 2008; Viana et al., 2008; Gietl and Klemm, 2009; Begum et al., 2010; Kertesz et al., 2010; Oliveira et al., 2010; Stone et al., 2010; Begum et al., 2011; Cheung et al., 2011; Pakbin et al., 2011; Tecer et al., 2012; Daher et al., 2013; Bove et al., 2014; Kuo et al., 2014). However, few SA studies have also been carried out using dispersion modeling approach (Colvile et al., 2003; Laupsa et al., 2009). Recent studies carried out in some of the urban areas in USA have concluded that metal/steel industries, motor exhaust and crustal emissions are major contributors of $PM_{2.5}$ concentrations in ambient air (Coutant et al., 2003; Thurston et al., 2011; Green et al., 2013; Hasheminassab et al., 2013; Sturtz et al., 2014). Studies conducted in European urban cities, motorized transport, crustal sources and mixed industrial/fuel–oil combustion are major sources of $PM_{2.5}$ and PM_{10} (Viana et al., 2008; Yin et al., 2010; Belis et al., 2013).

Since the last decade, many developing countries have included SA as an important component of UAQMP. In China, several studies have been carried out focusing identification, categorization and quantification of PM sources in ambient urban air and their correlation with human health (Song et al., 2006; Xie et al., 2008; Gu et al., 2010; Kong et al., 2010; Breitner et al., 2011; Gu et al., 2011; Leitte et al., 2011; Zhu et al., 2011; Liu et al., 2013; Wang et al., 2013). In India, a number of SA studies have been carried out apportioning SPM, PM_{10} and $PM_{2.5}$, using receptor modeling techniques (Khillare et al., 2004; Chowdhury et al., 2007; Gupta et al., 2007; Sharma et al., 2007; Chelani et al., 2008; Kothai et al., 2008; Srivastava and Jain, 2008; Srivastava et al., 2008; CPCB, 2010a; Kar et al., 2010; Shridhar et al., 2010; Gummeneni et al., 2011; Srimuruganandam and Nagendra, 2011; Pant and Harrison, 2012; Pant and Harrison, 2013; Tiwari et al., 2013; Sharma et al., 2014). One such similar study has recently been completed by CPCB, a regulatory body in India, covering six mega cities and presenting an integrated approach of measurements, chemical speciation and receptor modeling for assessing efficacy of UAQM strategies in mitigating PM_{10} ambient levels (CPCB, 2010a). Further, SA studies also provide a platform for the development of comprehensive and accurate emission inventories.

3.4. Emission inventory

A comprehensive emission inventory is the first step to develop an emission control strategy for selected pollutants. Compilation of an accurate emission inventory is an integral part of any UAQMP (Moussiopoulos, 2003; Miller et al., 2006). The product of the emission factor and traffic volume provides emission rate of motorized traffic (Esteves–Booth et al., 2002). Emission factors are normally expressed in grams of a pollutant per unit of distance traveled. The emission factor depends on the type of vehicle and fuel used, type of engine, I/M program, vintage of vehicles, driving cycle and average speed (Auto Fuel Policy, 2002). Emission inventory models are available, which allow users to vary the fleet structure, technology proportions, vehicle activity and proportions of driving conditions to estimate emissions and total fuel consumption (Boulter et al., 2007). U.S. EPA (2011b) describes various emission models including MOVES, MOBILE–6 and NMIM. Recently, Kota et al. (2014) have evaluated emission inventory of CO and NO_X from on–road vehicles using MOBILE 6.2 and MOVES in Southeast Texas, USA. They have found that MOBILE 6.2 estimations are more accurate when compared to MOVES. In UK, DEFRA (2011b) provides and maintains national atmospheric emission inventory. A majority of the EU countries use COPERT to estimate the emission load from motorized vehicles (Ekstrom et al., 2004). However, in Germany and Switzerland, "Handbook of Emission Factors" is also used for estimating the emission load from motorized sources (Keller and Zbinden, 2004). In Mexico, Wolf et al. (2009) have developed National Emissions Inventory for criteria pollutants and reported that mobile sources are responsible for 16% of PM_{10}, 52% of $PM_{2.5}$, 99% of CO, 82% of NO_X, 31% of NMVOC (non–methane volatile organic compounds) and 22% of ammonia (NH_3) emissions.

In China, MOBILE5B–China is used for motor vehicle emission inventories that are based on US EPA's MOBILE5b and PART5 (Hao et al., 2000; Hao and Wang, 2005; Zhou et al. 2010). Huo et al. (2009) have proposed a new link–based, bottom–up vehicle emission inventory method for Beijing City using the available on–road emission measurement data and activity survey data. Results have stated that total emissions from light–duty vehicles in Beijing urban area in 2004 have been 1 141 Mg of CO per day, 48 Mg of HC per day, and 32 Mg of NO_X per day. In South Africa, emission rates are estimated by simple multiplication of emission factor and traffic volume (DEAT, 2008). In India, the Indian Institute of Petroleum has estimated emission factors for two wheelers and cars based on standard Indian driving cycle (Pundir and Das, 1985). Further, the Automotive Research Association of India, in collaboration with CPCB, New Delhi has developed emission factors for all motorized vehicle types based on standard driving cycle and average vehicle speed (ARAI, 2007). In another study, Nagpure and Gurjar (2012) have developed a vehicular air pollution inventory (VAPI) model for Indian traffic conditions. In the recent past, Guttikunda and Calori (2013) have developed a GIS based emission inventory of air pollutants in Delhi City.

3.5. Air quality modeling

Air quality modeling plays an important role in formulating air pollution control and management strategies by providing guidelines for efficient air quality planning. Its main objective is to predict ambient air pollutant concentrations of one and more species in space and time as related to independent variables such as emission and meteorological parameters.

In USA, EPA recommended dispersion model, e.g. AERMOD (steady state dispersion model and an advanced version of ISC3) is used for regulatory purposes (Cimorelli et al., 2005; U.S. EPA, 2005). Another EPA recommended model, CALPUFF, is used for long–range transport (source–receptor distances of 50 km to several hundred kms.) of emissions from point, volume, area and line sources (Scire et al., 2000). CALINE 4 is used for highway sources in both urban and rural areas (Benson, 1984). In UK, ADMS–urban is used to assess the ambient air quality (Carruthers et al., 2000). In addition, CMAQ (Byun and Schere, 2006) is used to assess the ambient air quality (Williams et al., 2011). In developing countries, the availability of precise input data is one of the challenges (SEI, 2004). In spite of this, AirQuis modeling system has been developed in South Africa, which is being used for UAQMP in the city of eThekwini (NILU, 2007). Besides, in the designated airshed priority areas, CALPUFF is used to forecast the ambient air quality as a part of UAQMP (DEAT, 2008). At a local scale, Zunckel (2009) has developed an air pollution information network, which comprises guidelines/recommendations on how to carry out efficient air quality modeling. However, in Mexico City, coupled WRF–Chem (a photochemical model) is mainly used to forecast the pollutant concentrations (Tie et al., 2007; Ying et al., 2009; Li et al., 2011). In India, Gaussian based dispersion air quality models are used for regulatory compliances of ambient air quality (CPCB, 1998; CPCB, 2010a). In addition, a number of air quality models/codes have been validated/developed to predict ambient air quality in selected air quality control regions (Luhar and Patil, 1989; Khare and Sharma, 1999; Gokhale and Khare, 2005; Kesarkar et al., 2007; Khare et al., 2012; Nagendra et al., 2012; Sharma et al., 2013a; Sharma et al., 2013b). In addition, Elbir (2004), Elbir et al. (2010), Schipa et al. (2011), Gulliver and Briggs (2011) have used geographical information system (GIS) coupled with air quality models to forecast the pollutant concentrations in ambient urban environments. GIS based forecasting can estimate ambient air pollution levels at high temporal and spatial resolution, generate mapping and scenario results, which can further be compared with air quality standards. This can be integrated with socio–economic data at the receptor site, which may further assist in air pollution related exposure and health assessment and making the UAQMP more productive.

3.6. Air pollution exposure and health assessment

The ultimate goal of any urban air quality management plan is to ensure that the impact of air pollution on human health remains minimal. Past studies have reported that increasing PM concentrations deteriorate human health by affecting respiratory and cardiovascular systems (Dockery et al., 1993; Preutthipan et al., 2004; WHO, 2005; Pope and Dockery, 2006; Colais et al., 2012; Mustafic et.al., 2012; WHO, 2014). Therefore, air pollution exposure and health assessment becomes one of the significant components of UAQMP. Pope and Dockery (2006) have reviewed health effects of fine PM on humans and concluded that these effects are functions of concentrations as well as duration of the exposure. They have also reported that long–term exposure studies are more accurate in analyzing the cumulative effects than short–term exposure studies. In the USA, a few studies conducted in the past, have focused on the health impact of air pollution exposure in urban areas (Dockery et al., 1993; U.S. EPA, 2002; Lipfert et al., 2006; Dockery, 2009). In the UK, air pollution exposure assessment is one of the essential components of LAQMP (DEFRA, 2009a). In the European countries, studies have reported that high air pollution exposure level deteriorates the health of human beings (Gehring et al., 2013; Pascal et al., 2013; Raaschou–Nielsen et al., 2013). In one of the studies done in Australia, it has been observed that motor vehicle exhaust is responsible for causing cardiovascular and respiratory diseases (BTRE, 2005). Simpson et al. (2005) have observed 1% increase in daily total number of deaths per 10 mg/m^3 increase in $PM_{2.5}$ concentration. However, in developing countries, very few air pollution exposure and health assessment studies have been conducted so far (Han and Naeher, 2006). Steinar et al. (1997) have suggested incorporation of air pollution exposure and health assessment as an important component of UAQMP for developing countries in the Asian continent. Past studies indicate evidences of high risk of respiratory and cardiovascular diseases due to increased air pollution exposure levels (Terblanche et al., 1992; HEI, 2004; Wichmann and Voyi, 2005; Agarwal et al., 2006; Han and Naeher, 2006; Norman et al., 2007; Gurjar et al., 2010; HEI, 2010). Further, in South Africa, air pollution exposure and health assessment is not included in UAQMP, though many researchers have individually carried out exposure and health impact assessment studies (Wichmann and Voyi, 2005; Norman et al., 2007; DEAT, 2008). One of the studies carried out at Vaal triangle area (a notified priority area) have reported that out of the total surveyed population, 66% suffered from upper respiratory tract illnesses and 29% from lower respiratory tract illnesses (Terblanche et al., 1992). In another study conducted in the urban areas of South Africa, it has been estimated that ambient air pollution levels cause 3.7% of the national mortality from cardiopulmonary disease and 5.1% of mortality attributable to cancers of trachea, bronchus and lung in adults aged 30 years and older; and 1.1% of mortality from acute respiratory infections in children under 5 years of age (Norman et al., 2007). Huang et al. (2009) have analyzed the relationship between air pollution level, visibility and daily mortality rate in Shanghai, China. They have found that an increase in PM concentrations is significantly correlated with reducing visibility and increasing daily mortality rate. They have also suggested that visibility can act as surrogate of air quality in exposure and health assessment. In India, Chhabra et al. (2001) have described the role of ambient air pollution in chronic respiratory morbidity in residents of Delhi City. They have found positive relationship between increasing PM concentrations with chronic respiratory morbidity (i.e., chronic cough, phlegm, breathlessness, bronchitis and bronchial asthma). In an another study, HEI (2010) have reported that an increase in PM_{10} concentrations has increased risk of mortality in Chennai and Delhi cities of India; i.e., 0.4% and 0.15% increase per 10 μg/m^3, respectively. It is equivalent to mortality risk associated with PM_{10} exposure as observed in the first four studies conducted under PAPA (Public Health and Air Pollution in Asia) as well as in multi–city studies conducted in South Korea, Japan, Europe, and North America. Balakrishnan et al. (2011) have proposed a methodology using time–series analysis to quantify the effect of short–term exposure of PM_{10} on mortality in Chennai City, India. However, it can be concluded that developing countries need to focus more on source–specific exposure assessment studies especially for PM, because different sources of PM have different physio–chemical compositions and thus different biological potentials (Laden et al., 2000; Janssen et al., 2002).

3.7. The UAQM strategies

The UAQM strategies direct their efforts primarily to maintain acceptable ambient air quality in urban corridors by implementing different control measures, such as strict emission norms, improvement in fuel quality, efficient engine technology, I/M program, traffic fleet management within the specified air quality control regions and effective road and transport planning. The UAQM strategies are generally evaluated and selected on the basis of change in pollutant concentrations using air quality dispersion models. However, Sonawane et al. (2012) have reported that exposure and health impacts are more efficient criteria in selecting UAQM strategies. The authors have described that prior to implementation of UAQM strategies, it should be evaluated in terms of socio–economic and health consequences. The socio–economic evaluation studies need to take into account not only the cost of implementation of UAQM strategies, but also the consequent benefits arising from the actions such as health cost reduction. Steinar et al. (1997) have further stated that before implementation of UAQM strategies, cost–benefit analysis (CBA) or cost effectiveness analysis (CEA) must be carried out. Lieman et al. (2007) and Scorgie (2012) have described qualitative assessment and prioritization of UAQM strategies based on environmental benefits; technical viability; social acceptability and desirability; economic feasibility; and timeframe for implementation and environmental benefits realization. In the UK, after declaration of AQMA, all possible UAQM strategies are evaluated in terms of emission reduction, air quality improvement and cost effectiveness (DEFRA, 2009a; DEFRA, 2009b).

In USA, vehicular emissions are controlled through voluntary mobile source emission reduction programs under SIP (Wilson, 1997). The U.S. Department of Energy (2011) has launched a "Clean Cities Five Year Strategic Plan" aiming at reducing the petroleum–dependence in on–road transportation. In the UK and EU countries, the UAQM strategies are effectively implemented and regularly monitored at specific AQMAs (Corporation of London, 2003; Newcastle City Council, 2006; DEFRA, 2011c; Duffield, 2011; EEA, 2011b; EEA, 2013b; EEA 2013c). However, in developing countries, these are discreetly applied in various forms, e.g. mandatory use of clean fuel (CNG/LNG), use of catalytic convertors, restrictions on movements of heavy vehicles during day time and declaration of low emission zones (Molina and Molina, 2002; CPCB, 2006; Davis, 2008; DEAT, 2008; Molina et al., 2009; CAI–Asia, 2010b; CPCB, 2010b; Jazcilevich et al., 2011; Naiker et al., 2012; Salcedo et al., 2012; Zhong et al., 2013b). In Mexico, implementation of UAQM strategies has helped in reducing the concentration of criteria pollutants i.e., CO, SO_2, NO_2 and Pb, whereas concentrations of tropospheric O_3, PM_{10} and $PM_{2.5}$ are still at critical levels (Molina et al., 2007; Salcedo et al., 2012). In the recent past, Chavez–Baeza and Sheinbaum–Pardo (2014) have estimated that the implementation of low emitting vehicles and BRT in Mexico City Metropolitan Area can significantly reduce urban air pollution levels. In one of the studies, Stankovic et al. (2012) have evaluated sustainable urban air pollution management approach to tackle traffic related air pollution in the city of Banja Luka, Bosnia and Herzegovina through implementation of automatic traffic control system. Further, Menon–Choudhary and Shukla (2009) have described that such modern technologies, if conjoined with effective greenhouse gas mitigation controls, efficient policy governance with independent environment regulatory authority, can help to build an efficient and effective UAQMP in any developing country including India. Table 5 describes various UAQM strategies undertaken to maintain the acceptable air quality in different countries of the world.

3.8. Public participation

Public participation includes active response from citizens and stakeholders in urban air quality goal setting (Longhurst et al., 1996; DEAT, 2008). Karatzas et al. (2003) have described techniques for effective dissemination of urban air quality information to the public using mobile applications, street panels and mass media. Most of the EU countries are providing air quality information on websites and through publications (DNERI, 2004). In the USA, air quality information is shared with the public via AIRNow (AIRNow, 2011) which provides real time and forecast AQI for 300 cities. In addition to that, the "Window to my Environment" is a web–based tool that provides a wide range of federal, state, and local information about environmental conditions and features of the concerned area within the USA (U.S. EPA, 2011c). In South Africa, the information related to air quality is disseminated through web pages, newsletters and mass media (NILU, 2007). In India and China, the effective use of mass and electronic media, street panels and web pages has led to sharing the air quality of the urban areas with public (AQCIN, 2014; IITM, 2014).

4. Concluding Remarks

Motorized road transport is the dominant source of urban air pollution in almost all the countries of the world. However, increasing ambient air pollution at urban hot spots is one of the critical problems with frequent violations of NAAQS and/or WHO guidelines for pollutants like $PM_{2.5}$, PM_{10} and NO_X. An effective and efficient UAQMP may include all the key components, which may help in sustaining an acceptable ambient air quality. The UAQMPs can be implemented at national, city and/or local levels. In most of the developed countries, the UAQMPs are already being implemented successfully. The UAQMPs like SIP and LAQMP possess efficient communication system between national and local authorities, which ensures its effective implementation and thus maintain the acceptable ambient air quality. These UAQMPs have strict air quality standards/limits for all criteria and hazardous air pollutants; continuous real time air quality monitoring network along with display systems; efficient emission inventory model; air quality modeling and control practices and public participation. In London, congestion and road user charging schemes have been implemented successfully aiming to reduce vehicular pollution in specific defined zones which have significantly reduced CO_2, NO_X and PM_{10} concentrations by 16.4%, 13.4% and 6.9%, respectively (EEA, 2008). Further, Tonne et al. (2008, 2010) have reported significant reduction in PM and NO_X concentrations after the implementation of "congestion charging" in London which thereafter resulted in an increase in associated health benefits. Hasheminassab et al. (2014) have evaluated the impact of UAQM strategies in the reduction of $PM_{2.5}$ emissions from vehicular source using SA. Results have indicated that $PM_{2.5}$ emissions from the year 2002 to 2012 have been decreased by 24% and 21% in Los Angeles and Rubidoux, respectively. Another successful implementation of UAQMP can be observed at Cardiff and Norwich cities, where significant reductions in NO_2 concentrations have been achieved (Moorcroft and Dore, 2013). In USA, efficient and effective SIP in regions of Connecticut, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee and West Virginia and the District of Columbia has helped in achieving the goal of bringing down the concentrations of $PM_{2.5}$ within the prescribed standards (Cohan and Chen, 2014). Soret et al. (2011) and Soret et al. (2013) have described how the improvements in urban traffic fleet and vehicle technologies can significantly reduce ambient concentrations of NO_2 and PM_{10} in the city of Barcelona, Spain. Using WRF–ARW/HERMES/CMAQ modeling system at very high spatial and temporal resolutions, it is observed that NO_2 and PM_{10} reductions are in the range of 15 $\mu g/m^3$ and 5 $\mu g/m^3$, respectively. In addition, Henschel et al. (2012) have reviewed control strategies that have been implemented to reduce air pollution levels and their health impacts. They have reported that interventions have successfully reduced air pollution levels and increased associated health benefits, mainly through reduced cardiovascular and/or respiratory mortality and/or morbidity. Further, Pope et al. (2009) have observed that a reduction in the exposure to ambient fine PM concentrations has resulted in significant and measurable improvements in life expectancy in 211 county units in 51 U.S. metropolitan areas. The decrease of 10 $\mu g/m^3$ in the concentration of $PM_{2.5}$ has been associated with an increase in mean life expectancy of 0.61 years in urban and densely populated counties. Later, Correia et al. (2013) carried out similar studies in 545 counties in USA and found that reductions in $PM_{2.5}$ concentrations due to implementation of efficient and effective UAQM strategies resulted in an increase in life expectancy. Similarly, in EEA member countries, a decrease in emission levels of NO_X and $PM_{2.5}$ from transport sector from 1990 to 2005 has resulted in a reduction in health impacts in the range of 2.5% in Bulgaria to 25% in Luxembourg and Switzerland (EEA, 2010). In another study, involving 25 cities of 12 European countries, it has been estimated that decrease of long-term exposure to $PM_{2.5}$ to 10 $\mu g/m^3$ can prevent more than 19 000 premature deaths, annually (APHEKOM, 2011). In addition, Pererz et al. (2009) have estimated that reducing the mean PM_{10} exposure by 30 mg/m^3 has resulted in 3 500 lesser deaths, 1 800 lesser hospitalizations for cardio–respiratory diseases, 5 100 lesser cases of chronic bronchitis among adults, 31 100 lesser cases of acute bronchitis among children and 54 000 lesser asthma attacks among children and adults. As a consequence, the mean total monetary benefits have been estimated to be 6 400 million Euros per year. Table 6 has described some examples of success stories of achieving health benefits due to reduction in PM concentrations after implementing UAQM strategies. However, in most of the developing countries, UAQMPs are either in process of development or do not exist at all. Hence, looking at the increasing urbanization globally, the need of the hour is to equip the air quality regulatory authorities with effective and efficient UAQMP, which may help them to maintain the urban quality within the prescribed limits/standards.

Table 5. *UAQM strategies of developed and developing countries*

UAQM Strategies	US [a]	UK [b]	EU [c]	Australia [d]	British Columbia [e]	Japan [f]	Hong Kong [g]	Singapore [h]	Mexico [i]	Thailand [j]	South Africa [k]	China [l]	India [m]
Alternative fuel option in vehicles	x	x	x	x	x	x	x	x	x	x	o	x	x
Improvement in fuel quality	x	x	x	x	x	x	x	x	x	o	o	x	x
Fitting of catalytic converter	x	x	x	x	x	x	x	x	x	o	o	o	o
Inspection and maintenance program	x	x	x	x	x	x	x	x	x	o	o	o	o
Use of low and zero emission vehicles	x	x	x	x	x	x	x	o	x	o	o	o	o
Banned on street parking	x	x	x	x	x	x	x	x	x	o	o	o	o
Support for cycling	x	x	x	x	x	x	x	x	o	x	–	x	n
Congestion charging	x	x	x	x	–	–	–	–	x	n	n	n	n
Specific bus corridors	x	x	x	x	x	x	o	o	x	o	o	o	o
Pedestrians corridors	x	x	x	x	x	x	o	o	x	o	o	o	o
Low emission zone	–	x	x	o	–	–	–	n	o	n	n	n	n
Banned on entry of old vehicles in air quality control regions	x	x	x	x	x	x	x	x	x	o	o	o	o
Banned of heavy good vehicles in air quality control regions	x	x	x	x	x	x	x	x	x	o	o	o	o
Banned on idling of vehicles at traffic signal	x	x	x	o	x	–	o	–	–	–	n	–	n
Split Cycle Offset Optimization Technique (SCOOT) system	o	x	x	–	–	–	n	n	–	n	n	n	n
Intelligent transport system	x	x	x	–	–	–	–	–	–	–	n	n	n
Banned on smoky vehicle	x	x	x	x	x	x	x	x	x	x	o	o	o
On–board diagnostic system in vehicle	x	x	x	x	x	x	x	x	x	x	o	o	o
Subsidy on registration tax on environment–friendly vehicles	x	x	x	–	x	x	–	–	x	n	n	n	n
Mass rapid transport	x	x	x	x	x	x	x	x	x	x	o	x	x
Encouraging carpools	x	x	x	x	x	–	–	x	–	o	n	n	n
Maintenances of road infrastructure	x	x	x	o	x	x	o	x	x	o	o	o	o
Stringent emission norms	x	x	x	x	x	x	x	x	x	o	o	x	x
Reduction in diesel vehicles	x	x	x	x	x	x	x	x	x	o	n	n	n

[a] *CULS (2014), U.S. EPA (2011a)*
[b] *Corporation of London (2003), Newcastle City Council (2006)*
[c] *EEA (2011b), EEA (2013b), EEA (2013c), EU-Transport and Environment (2014)*
[d] *NSW Government (2009), Commonwealth of Australia (2011), EPA (2007), Todd et al. (2011)*
[e] *B.C. Government (2008)*
[f] *CEC (2005), CEC (2011)*
[g] *Environmental Bureau, Hong Kong (2013), Edesess (2011)*
[h] *ADB (2006a), NEA (2014)*
[i] *Molina and Molina (2002), Davis (2008), Molina et al. (2009), Molina et al. (2010), Jazcilevich et al. (2011), Salcedo et al. (2012), Chavez-Baeza and Sheinbaum-Pardo (2014)*
[j] *KEI (2002); IGES (2007), CAI-Asia (2010b)*
[k] *DEAT (2008), Naiker et al. (2012)*
[l] *Hao et al. (2005), Zhou et al. (2010), Wu et al. (2011), Zhong et al. (2013b)*
[m] *CPCB (2006), CPCB (2010b)*
x=properly implemented, o=partially implemented, n=not implemented, – information not available

Table 6. *Health benefits of implementation of UAQM strategies*

Country	References	Case Study	Main Outcomes
USA	Friedman et al. (2001) Pope et al. (2009) Peel et al. (2010) Correia et al. (2013)	• Traffic management during Olympic games period in 1996 at Atlanta • Air pollution health impacts result compared with baseline in surrounding years • Short as well as long term management	• Significantly decreased in PM (16.1%) and O_3 (13–30%) concentrations during Olympic period compared to baseline period • Significant decrease in number of hospital visit by Asthma patients • Increase in mean life expectancy of years in 545 county in US due to decrease in PM_{10} concentrations
European Environment Agency Members	EEA (2010) APHEKOM (2011)	• Impacts assessment of European Air Emission Policies • Long term traffic management	• Air quality and public health improved in all 32 EEA members states • Reduction in PM and NO_2 concentrations • Decrease in years of life lost in range of 2.5–25% through EEA members
UK	Tonne et al. (2008) Tonne et al. (2010)	• The London congestion charging scheme • Long term traffic management	• Decrease in NO_2 and PM_{10} concentration level in designated area • Increase in years life gained of resident live within congestion charging zone • Significant reduction in hospital admission of bronchitis patients
Sweden	Johansson et al. (2009)	• The Stockholm congestion charging scheme • Long term traffic management	• Significant decrease in NO_X (10%) and PM_{10} (7.6%) concentration within CCZ compared with previous year • 210 year life gained per 100 000 persons from Greater Stockholm over a 10 year period
China	Huang et al. (2009b) Li et al. (2010)	• Traffic management during Olympic games in Beijing in 2008 • Short term traffic management	• Significant decrease in asthma patients visit to hospitals. • Increase in 10 $\mu g/m^3$ of $PM_{2.5}$ and 10 ppb of O_3 found to be associated with increase in 2%–4.4% in asthma outpatients visits

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