AIR POLLUTION EFFECT ON URBAN AREAS

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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).

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 1describes 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_3concentrations. 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_2concentrations 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 μg/m3 ±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 μg/m3 (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 CO2, 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 in Delhi and Mumbai is about 76–90% for CO, 66–74% for NO_x, 512% 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

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 obtaineoptimal air quality–monitoring network in Riyadh City, Saudi Arabia. Table 4 describes various air quality-monitoring networks being used in different countries.

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 (SLAMSI), (ii) National air monitoring stations (NAMS) (Hi) Special purpose monitor station (SPMS) for very specific or short-term monitoring goals	Both	CO, Pb, NO_2O_3, PM, $S0_2$	www.airnow.gov
UK	Rural (R), Traffic (T), Industrial (1) and Background (B). Automatic Rural and Urban Network (ARUN) is the largest monitoring network.	Both	NO_x $S0_2$, O_3, CO and PM (PMicand PMjs)	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_2SO_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, 0_3, $S0_2$ PM_{10} and PM_{35}	www.environment.nsw.gov.au/aqms
British Columbia	Continuous (hourly), non-continuous [24 hourly) and mobile (episodic).	Both	CO, $N0_3$, 0_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, $N0_2$, SO_2, PM_{20}, $PM_{2.5}$, 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, 0_3,	www.aqicn.org
India	National Ambient Air Quality Programme (NAAQM).	Both	$S0_2$, NO_x, SPM, CO and PM_{10},	http://164.100.43.188/cpcbnew

3.3. 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 airpollution at urban hot spots is one of the critical problems with frequent violations of NAAQS and/or WHO guidelines for pollutants like PM_{25}, $PM_{10}$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 monitoringnetwork 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_{25}emissions from vehicular source using SA. Results have indicated that PM_{25}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_{25} 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.

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