The Status of $PM_{2.5}$ Pollution in Asia and Direction toward Solving the Issue

Keiichi SATO[1]* and Toshimasa OHARA[2]

[1]**Asia Center for Air Pollution Research*
1182 Sowa, Nishi-ku, Niigata City, 950-2144, Japan
[2] *Fukushima Branch, National Institute for Environmental Studies*
10-2 Fukasaku, Miharu, Fukushima, 963-7700, Japan
**E-mail : ksato@acap.asia*

Abstract

$PM_{2.5}$ air pollution at urban and regional scales is a serious environmental issue in Asia. Developing counties in South and Southeast Asia are facing an especially severe situation with urban $PM_{2.5}$ pollution. Also, transboundary air pollution results in high $PM_{2.5}$ concentrations over wide regions leeward of the source country. Additionally, long-range transport of Asian dust aerosols in Northeast Asia and biomass burning in Southeast Asia has resulted in regional haze episodes. This paper provides an overview of temporal trends, focusing on $PM_{2.5}$ pollution in Asian region, ambient standard levels in each country and regional characteristics. It also discusses the way forward toward $PM_{2.5}$ mitigation.

Key words : ambient standard, Asia, $PM_{2.5}$ pollution, regional characteristics, trend

1. Introduction

$PM_{2.5}$ particulate matter, called "fine" particulates, consists primarily of particles directly emitted into the atmosphere and, secondarily, those that are formed in the atmosphere from gaseous pollutants as a result of atmospheric chemistry (secondary formation). Generally, fine particulates pose a greater health risk because these particles can deposit deep in the lungs and they contain chemicals that are particularly harmful to health. In addition to the health impacts, these particles can reside in the atmosphere for long periods of time and are major contributors to reduced visibility. Asia has recently become the region with the world's most massive air pollutant emissions air pollutants, surpassing those of Europe and North America (EANET, 2015). As a result, $PM_{2.5}$ pollution has become a serious environmental issue in Asia, posing high health risks, impacts on ecosystems and regional-scale climate change.

In the second part of this special issue on $PM_{2.5}$ pollution, four papers were contributed from China, Mongolia, South Korea and Vietnam. The paper from China, "Air Quality Management Achievements, Challenges and the Way Forward in China: Including $PM_{2.5}$ and Other Major Air Pollutants," by Yao (2018), gave an overview of that country's air pollution status, action plans being implemented and future challenges in air pollution mitigation. Annual $PM_{2.5}$ concentrations in several cities ranged from 12 to 158 μg/m^3 in 2016, with an average of 47 μg/m^3; and the percentage of days with $PM_{2.5}$ exceeding the standard was 14.7%. Major air pollutants such as $PM_{2.5}$ and PM_{10} decreased between 2013 and 2016, achieving the Action Plan's target in advance.

The paper from Mongolia, "Current Status of $PM_{2.5}$ Pollution and its Mitigation in Ulaanbaatar City of Mongolia," by Dugerjav *et al.* (2018) describes current status of PM_{10} and $PM_{2.5}$ distribution and time variations in Ulaanbaatar, and current and future air pollution mitigation policies in Mongolia. The monthly average $PM_{2.5}$ concentration in Ulaanbaatar was 256 μg/m^3 in December 2016, which was more than 25 times the annual mean of the WHO guideline (10 μg/m^3), and five and ten times, respectively, higher than the daily mean (50 μg/m^3) and annual mean (25 μg/m^3) of Mongolia's National Air Quality Standard. To reduce air pollution, the Mongolian Government made the decision to ban the consumption of raw coal in Ulaanbaatar starting from 2019.

The paper from South Korea, "Chemical composition of the ambient $PM_{2.5}$ in 2014 over Korea," by Sung *et al.* (2018), describes characteristics of $PM_{2.5}$ mass and composition concentrations in 2014 in six South Korean cities. The annual mean $PM_{2.5}$ concentrations were 25.9, 28.1, 27.4, 24.1, 15.5, 22.4 μg/m^3 in Seoul, Daejeon, Gwangju, Baengnyeong, Jeju and Ulsan, respectively. Some cities have $PM_{2.5}$ levels exceeding the annual mean (25 μg/m^3) of South Korea's National Air Quality Standard. The dataset demonstrates regional characteristics in Korea that will be useful in establishing effective measures for reducing $PM_{2.5}$.

The paper from Vietnam, "Current Status of $PM_{2.5}$ Pollution and its Mitigation in Vietnam," by Nguyen *et al.* (2018), provides a comprehensive review of the state of $PM_{2.5}$ pollution, emission sources, health impacts and mitigation in Vietnam. The annual mean $PM_{2.5}$ concentration in Ha Noi, Ha Long and Ho Chi Minh City between 2013 and 2017 exceeded the annual mean (25 µg/m^3) of National Air Quality Standard in Vietnam. Vietnam has been acting in various ways to mitigate $PM_{2.5}$ pollution through efforts by the government, non-government organizations, media, communities and individuals.

The above-listed papers are important in that they demonstrate the current status of PM pollution in East Asian countries. To discuss the $PM_{2.5}$ pollution issues in Asia more comprehensively, this paper provide an overview of the current status of $PM_{2.5}$ pollution in the Asian region overall and discusses future directions for improving that pollution.

2. Status of $PM_{2.5}$ Pollution in Asia

2.1 $PM_{2.5}$ Standards in Asia

An air quality standard is the maximum amount of air pollutant allowable to prevent harm human health, decreased visibility and damage to animals, crops, vegetation and buildings. Establishment of ambient air quality standards and monitoring of their compliance are among the important measures to protect the public health from the adverse effects of air pollution. Air quality standards for particulate matter usually prescribe mass concentrations of PM_{10} and $PM_{2.5}$ because PM_{10} reaches the bronchial pathways and lungs and $PM_{2.5}$ penetrates deep into the lungs and may enter the blood system. In 2005, the World Health Organization (WHO) updated its air quality guidelines (AQG) associated with adverse effects on chronic cardiovascular and respiratory diseases in epidemiologic studies (WHO, 2006). The AQG points out that a $PM_{2.5}$ concentration of 10 µg/m^3 is the lowest level at which total cardiopulmonary and lung cancer mortality have been shown to increase with greater than 95% confidence in response to long-term exposure to $PM_{2.5}$. In addition to the AQG, the WHO also introduced three interim target (IT) levels at which specified mortality responses are indicated based on published risk coefficients from multi-centre studies and meta-analyses (Table 1).

National or local governments in the Asian region have adopted a range of air quality standards, most of which are based on international guidelines, such as the WHO's AQG and the National Ambient Air Quality Standards (NAAQS) of the United States Environmental Protection Agency (USEPA), that prevailed at the time of their development. It would be desirable for national or local governments to develop standards after considering prevailing exposure levels, meteorological and topographical conditions, socio-economic levels, natural background concentrations and population susceptibility in their communities. Table 2 provides a summary of PM_{10} and $PM_{2.5}$ standards in South and East Asian countries (CAI-Asia, 2010; DENR, 2018; JICA, 2017; Kutlar Joss *et al.*, 2017; MOEJ, 2018). Some countries such as Afghanistan, Brunei Darussalam, Cambodia, Maldives, Myanmar and North Korea have not yet established air quality standards for PM_{10} or $PM_{2.5}$, but Cambodia has an air quality standard for total suspended particles (TSP). Japan has an air quality standard for suspended particulate matter (SPM) instead of PM_{10}, which is approximately equivalent to PM_7. Bhutan, China and India have several levels of quality standards classified by industrial, residential and natural conservation areas. Singapore sets air quality targets to be achieved by 2020.

Compared with the WHO's AQG and the USEPA's NAAQS, all current PM_{10} standards in Asia are equivalent to or lower than the NAAQS (150 µg/m^3 for 24-hour values), but they are higher than the AQG (50 µg/m^3 for 24-hour values and 25 µg/m^3 for the annual mean). Establishment of $PM_{2.5}$ standards in Asian countries is moving ahead more slowly compared to that of PM_{10}. There are only 12 countries that have established $PM_{2.5}$ standards. Many countries set $PM_{2.5}$ standards equivalent to or greater than the NAAQS (35 µg/m^3 for 24-hour values and 12 µg/m^3 as an annual mean primary standard) and AQG (20 µg/m^3 for 24-hour values and 10 µg/m^3 for the annual mean). The main reason for this is lack of epidemiological data on $PM_{2.5}$ and insufficient nationwide monitoring data. It is important to establish a sufficient number of monitoring stations for assessing compliance to air quality standards and effectiveness of air quality policies.

Table 1 WHO air quality guidelines and interim targets for particulate matter.

	Annual mean $PM_{2.5}$ (µg/m^3)	24-hour $PM_{2.5}$ (µg/m^3)	Basis of level selected for annual mean
Interim target-1 (IT-1)	35	75	Associated with about 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	25	50	Lowers the risk of premature mortality by approximately 6% (2-11%) relative to the IT-1 level.
Interim target-3 (IT-3)	15	37.5	Reduces the mortality risk by approximately 6% (2-11%) relative to the IT-2 level.
Air quality guideline (AQG)	10	25	Lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$.

Table 2 Summary of PM_{10} and $PM_{2.5}$ standards in South and East Asian countries.

Country	Annual mean PM_{10}（μg/m^3）	24-hour PM_{10}（μg/m^3）	Annual mean $PM_{2.5}$（μg/m^3）	24-hour $PM_{2.5}$（μg/m^3）
Bangladesh	50	150	15	65
Bhutan（mixed）[1]	60	100	—	—
China : Grade Ⅱ[2]	70	150	35	75
Hong Kong SAR	50	100	35	75
India[3]	60	100	40	60
Iran	20	154	10	35
Indonesia	—	150	—	—
Japan	—	—	15	35
Lao PDR	120	50	—	—
Malaysia	50	150	—	—
Mongolia	50	150	25	50
Myanmar	—	—	—	—
Nepal	—	120	—	—
Pakistan	120	150	15	35
Philippines[4]	60	150	25	50
South Korea	50	100	25	50
Singapore[5]	20	50	12	37.5
Sri Lanka	50	100	25	50
Taiwan, Province of China	65	125	15	35
Thailand	50	120	25	50
Vietnam	50	150	—	—

1 = Areas where residential, commercial or both activities take place. 2 = Applies to residential areas, mixed commercial/residential areas, cultural, industrial and rural areas. 3 = Applies to industrial, residential, rural and other areas. 4 = Air quality guideline values. 5 = Air quality targets by 2020.

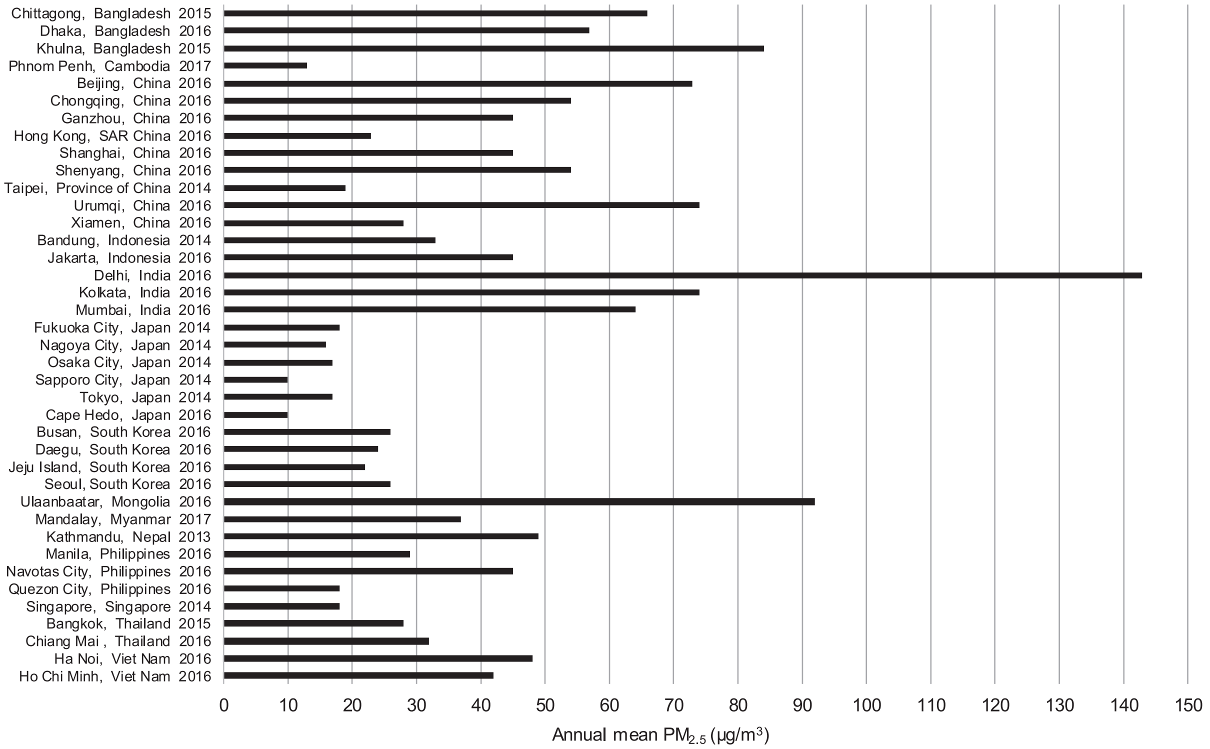

Fig. 1 Annual mean PM2.5 concentrations in South and East Asian countries.（Year of measurement is shown in the y-axis label）

2.2 Regional Characteristic $PM_{2.5}$ Concentrations in Asia

Figure 1 shows annual mean $PM_{2.5}$ concentrations at selected sites in South and East Asian countries（EANET, 2018 ; WHO, 2018）. The data show annual means for one year between 2014 and 2017. $PM_{2.5}$

concentrations at some sites in Bangladesh, China, India and Mongolia were more than twice the respective national air quality standards. These countries face severe air pollution, so $PM_{2.5}$ source analysis has been implemented. Source apportionment of $PM_{2.5}$ in Dhaka, Bangladesh during 1993−1994 showed that $PM_{2.5}$ was mainly attributed to natural gas/diesel burning (46%), motor vehicles (29%) and metal smelting (10%) (CAI-Asia, 2006). Source contributions to $PM_{2.5}$ during 2013 were determined for 25 Chinese provincial capitals and municipalities using the Community Multiscale Air Quality (CMAQ) model (Qiao *et al.*, 2018). Industrial or residential sources were predicted to be the largest contributors to $PM_{2.5}$ in all cities, with annually fractional contributions of 25.0−38.6% and 9.6−27%, respectively. Secondary $PM_{2.5}$ accounted for 47−63% of annual $PM_{2.5}$ concentrations and contributed to as much as 70% of daily $PM_{2.5}$ concentrations on polluted days. Chemical characterization of $PM_{2.5}$ was carried out in Delhi, India during 2013−2014, and a Positive Matrix Factorization (PMF) model was applied for source apportionment of $PM_{2.5}$ mass concentration (Sharma *et al.*, 2016). The major sources of $PM_{2.5}$ were secondary aerosols (21.3%), soil dust (20.5%), vehicle emissions (19.7%), biomass burning (14.3%) and fossil fuel combustion (13.7%). Some studies implemented chemical characterization of $PM_{2.5}$ in Ulaanbaatar, Mongolia, finding coal combustion processes to be a major contributor to $PM_{2.5}$ during air pollution episodes in autumn and winter (Baldorj & Sato, 2016; Davy *et al.*, 2011). These source analysis results would be helpful in developing measures to reduce annual $PM_{2.5}$ concentrations in Asian cities.

For other countries, annual $PM_{2.5}$ concentrations at sites in Myanmar, Nepal, Philippines, Thailand and Vietnam exceeded 30 μg/m^3. Among these countries, Thailand and Philippines adopted air quality standards or guidelines for $PM_{2.5}$. Limited air quality data, especially in developing countries, is an obstacle to evaluating potential air quality impacts originating from various sources and establishing air quality standards for $PM_{2.5}$. Annual $PM_{2.5}$ concentrations at the sites in Cambodia, Japan, South Korea and Singapore were less than 30 μg/m^3, but still exceeded the WHO's AQG. Although adverse effects on health cannot be entirely ruled out below the AQG level for $PM_{2.5}$, the annual mean AQG value represents a $PM_{2.5}$ concentration that has not only been shown to be achievable in large urban areas in highly developed countries, but also expected to significantly reduce the health risks if attained (WHO, 2006). In addition to the AQG value, three interim targets (IT) for $PM_{2.5}$ are presented because it is difficult for developing countries to attain the AQG. These targets aim to promote a shift from high air pollutant concentrations, which have serious acute health consequences, toward lower air pollutant concentrations.

2.3 $PM_{2.5}$ Concentration Trends in Asia

Compared to other air pollutants, there are limited long-term monitoring data on $PM_{2.5}$ in the Asian region. Some studies have evaluated trends in $PM_{2.5}$ using data from air-pollution monitoring stations in Tokyo (Hara *et al.*, 2013; Wakamatsu *et al.*, 2013). The annual average $PM_{2.5}$ concentration in Tokyo declined by 49.8% from 29.3 μg/m^3 in 2001 to 14.7 μg/m^3 in 2010. Significant positive correlations were found between traffic volume and $PM_{2.5}$ concentration at the four stations in Tokyo, and the average concentrations of $PM_{2.5}$ per traffic volume have also decreased since 2001 (Hara *et al.*, 2013). The decrease in traffic volume resulting from the travel restriction regulations implemented in October 2003, which restrict diesel vehicles not in compliance from being driven in Tokyo. New engines and the installation of exhaust gas treatment devices, such as diesel particulate filters complying with regulations in 2005 were effective at reducing $PM_{2.5}$ (Tokyo Metropolitan Government, 2018; JAMA, 2018). The results of trend analysis suggest that reduction in traffic volume as well as improvements in engine design and the installation of exhaust gas treatment systems may have improved air quality.

Lang *et al.* (2017) investigated long-term trends in $PM_{2.5}$ from 2000 to 2015 in Beijing, based on intensive observation and a comprehensive investigation of literature on $PM_{2.5}$ and its chemical components. The annual average concentration of $PM_{2.5}$ generally decreased by 1.5 μg/m^3 per year from 2000 to 2015 thanks to implementation of pollution control measures. In winter, the most polluted season, $PM_{2.5}$ concentrations were affected by emission control efforts and meteorological conditions. As for trends in chemical components of $PM_{2.5}$, the organic carbon (OC)/elementary carbon (EC) ratio and secondary organic carbon (SOC)/OC ratios showed an increasing trend, which implies that pollution from secondary carbonaceous species is becoming serious. The proportion of secondary inorganic aerosol (SIA) in $PM_{2.5}$ increased at a rate of 0.7% per year. Although the emission mitigation measures implemented in Beijing have reduced primary $PM_{2.5}$ effectively, special attention should be paid to controlling secondary components to improve the air quality in Beijing further.

Kim and Lee (2018) provided an analysis of trends in air pollutant concentrations in the Seoul Metropolitan Area (SMA) as policies were applied. The concentrations of $PM_{2.5}$ and PM_{10} in Seoul have decreased since 2003. The concentrations of primary air pollutants decreased drastically during the 1980s and 1990s due to strict regulations on fuels and emission standards. Even with strict regulations, however, the number of emission sources has increased as living standards have improved, the result being that overall levels of air pollutants have not decreased since the early 2000s. To improve air quality in the SMA, the Korean Government enacted the "Special Act on the Improvement of Air Quality in Seoul Metropolitan Area" in 2003 to control emissions from diesel vehicles. Therefore, the main reason for this decreasing trend may be reduction of air pollutant emissions in the SMA, though meteorological conditions have also contributed to the decreasing trend. Emissions of PM_{10}, NOx, SOx and Volatile Organic Compounds (VOCs) in the SMA decreased by 33%, 30%, 40% and 9%, respectively, in 2014 compared to 2007.

To elucidate spatial coverage of $PM_{2.5}$ trends in the Asian region, some studies have used satellite-retrieved $PM_{2.5}$ concentration data. Ma *et al.* (2016) estimated ambient $PM_{2.5}$ concentrations from 2004 to 2013 in China at a 0.1° resolution using the most recent satellite data. Their analysis revealed an annual mean $PM_{2.5}$ increase of 1.97 μg/m^3 between 2004 and 2007 and a decrease of 0.46 μg/m^3 between 2008 and 2013 for China overall. Similar changes in trends were observed in the Beijing-Tianjin Metropolitan Region, Yangtze River Delta and Pearl River Delta. These data can provide historical $PM_{2.5}$ estimates in China before establishment of the regulatory $PM_{2.5}$ monitoring network, and will enhance research on long-term $PM_{2.5}$ health effects in China. Shi *et al.* (2018) estimated premature mortality attributable to $PM_{2.5}$ in South and Southeast Asia (SSEA) from 1999 to 2014 using satellite-retrieved $PM_{2.5}$ concentrations with a 0.01° resolution. The estimated number of $PM_{2.5}$-induced average annual premature deaths in SSEA increased from 1,179,400 in 1999 to 1,724,900 in 2014. These results suggest that strict $PM_{2.5}$ concentration controls are urgently required in SSEA.

3. The Way forward for $PM_{2.5}$ Mitigation

$PM_{2.5}$ mitigation can make a significant contribution toward promoting healthy life and well-being and the creation of safe, sustainable cities. As air pollution is a major health risk and economic burden, policy makers should implement national air pollution control measures. Reduction of exposure to $PM_{2.5}$ would not only require a reduction of primary $PM_{2.5}$ emissions but also of precursor emissions (SO_2, NO_x, NH_3, VOCs) to secondary $PM_{2.5}$. Regional scale emission reductions are essential for reducing $PM_{2.5}$ levels.

$PM_{2.5}$ pollution involves new issues such as the link between urban air pollution and regional/hemispheric air pollution, as well as the relationship between air pollution and climate change. Reduction of $PM_{2.5}$ precursor emissions can also be expected to mitigate other atmospheric pollutants such as ozone. Accordingly, extended assessment of the state of $PM_{2.5}$ should be strengthened in Asia. Ground-based monitoring is a key component of assessment, particularly at the city scale, and countries need to enhance ground-level monitoring networks. With ground-based monitoring alone, however, it is hard to monitor spatial and temporal variability. Satellite-based observations need to be combined with data from ground-based monitoring. Estimation of the disease burden due to $PM_{2.5}$ is being improved with better data and improved methods leading to improved accuracy. The results of research and studies on effects of each chemical component of $PM_{2.5}$, and combined health impacts with other pollutants such as nitrogen oxides, ozone and natural dust will help improve disease burden estimates. Air quality modeling and emission inventories are other key components to assess in elucidating formation mechanisms of $PM_{2.5}$ pollution, for predicting its status based on emission scenarios in the future, and for policy making toward emission reduction for pollution mitigation.

UNEP and the WMO reported that reducing some air pollutants can help limit near-term global warming and mitigate the impacts on human health and agricultural crops (UNEP/WMO, 2011). Reduction of SLCP (short-lived climate pollutants) such as ozone and black carbon—a chemical component of $PM_{2.5}$—has the co-benefit of mitigating global warming as well as air pollution. Additionally, because the effects of reducing SLCP are more immediate than those of reducing long-lived greenhouse gas such as CO_2, which has a long time lag to its reduction effect, SLCP reduction receives the most attention as a global warming mitigation measure with more immediate effects. Particularly, the SLCP co-benefit approach is an effective measure in Asian regions such as China where serious air pollution occurs.

Co-control planning or "an integrated multi-pollutant approach for controls" is also recommended for planning control measures that can simultaneously reduce several pollutants including $PM_{2.5}$, and therefore can be highly cost-effective. Co-control air quality planning optimizes trade-offs between pollutants, impacts and benefits. This approach is extremely important in Asia, where many kinds of pollutants can be found at high levels beyond ambient air quality standards.

For solving the issue of $PM_{2.5}$ pollution in the developing countries of Asia, international transfer of clean technology and systems from developed countries should be promoted. For example, Japan has useful experience and technologies for reducing serious air pollution. In Japan, serious air pollution occurred in urban and industrial areas during the period of the high economic growth in the 1960s and was at comparable levels to particulate pollution in China currently. Japan's air pollution has been improved through much effort from central and local governments, scientists and engineers, private companies and other actors. Such experience and clean technologies should be transferred to developing countries where they can play an important role in solving the issue of air pollution.

There is a need for closer cooperation among all organizations, initiatives and networks to reduce regional atmospheric pollution in Asia. EANET (Acid Deposition Monitoring Network in East Asia) has established linkages with many regional and sub-regional initiatives, networks and programs involved in the protection of the atmospheric environment (EANET, 2018). An Asia Pacific Clean Air Partnership (APCAP) has been recently proposed to establish common understanding among scientists and policy makers and develop an international initiative for an integrated approach to air pollution among Asian scientists (EANET, 2015).

4. Summary and Conclusions

An overview of the current status of $PM_{2.5}$ in Asian countries is given here from the viewpoint of ambient standard levels in each country, regional characteristics and temporal trends. Many developing countries in Asia lack sufficient air quality data, creating an obstacle to evaluating potential air quality impacts originating from various sources and establishing air quality standards for $PM_{2.5}$. Enhancing the air quality monitoring network in the Asian region would be the first step toward tackling PM pollution issues. In addition, the present paper has discussed future directions for improving $PM_{2.5}$ pollution in Asia. Air pollution management toward $PM_{2.5}$ mitigation is expected to be strengthened at the local, national and region levels, with an aim to reduce the adverse impacts of air pollution and to recover Asia's clean blue skies.

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Keiichi Sato

He received Ph. D. majored in Environmental Chemistry at Osaka Prefecture University in 2003. Then, he worked as a postdoctoral fellow at National Institute of Environmental Studies (2003-2005) and an assistant professor at Chuo University (2005-2008). He has been worked as a chief senior researcher at Asia Center of Asia Center for Air Pollution Research (ACAP) since 2008. At ACAP, he has been involved in technical assistance and data compiling for air concentration monitoring in Acid Deposition Monitoring Network in East Asia (EANET) and also jointed research projects in East Asian countries (Korea, China, Thailand, Mongolia etc.) focusing on atmospheric pollutants observations and modeling studies.

Toshimasa Ohara

Toshimasa Ohara, Ph. D., is a fellow at the National Institute for Environmental Studies (NIES). His research fields are emission inventory development and chemical transport modeling of air pollutants at the urban and regional scales in Japan and East Asia. He also presides over the Japan Society for Atmospheric Environment. Currently he is research director at the Fukushima branch of NIES, and leads the Environmental Emergency Research Program for contributing to environmental reconstruction and creation in Fukushima.

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