IMPROVING AIR QUALITY MONITORING IN ASIA

A GOOD PRACTICE GUIDANCE

Final Report

CLEAN AIR ASIA

ADB

IMPROVING AIR QUALITY MONITORING IN ASIA

A GOOD PRACTICE GUIDANCE

Final Report

CLEAN AIR ASIA

ADB

Improving Air Quality Monitoring in Asia: A Good Practice Guidance
Mandaluyong City, Philippines: Asian Development Bank, 2013.

Note:
In this publication, "$" refers to US dollars.
Unless otherwise stated, boxes, figures and tables without explicit sources were prepared by the authors.

6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
Tel +63 2 632 4444
Fax +63 2 636 2444
www.adb.org

Cover Photo:
Dr. rer Nat. Ronald Macatangay, U.P. Institute of Environmental Science and Meteorology

LIST OF ABBREVIATIONS

AAQD (CAN)	Ambient Air Quality Directives (Canada)
AMS	Air Monitoring Stations
APDLN	Air Pollution Distance Learning Network
APHI	Air Pollution Health Index
API	Air Pollution Index
APTI	Air Pollution Training Institute
AQ	Air Quality
AQI	Air Quality Index
AQM	Air Quality Management
As	Arsenic
BAGA	Breathe Always Good Air
BAN	Bangladesh
BAQ	Better Air Quality
BHU	Bhutan
CAI	Comprehensive Air-quality Index
CAQI	Common Air Quality Index
CEA	Central Environment Agency
CENMA	Center for Natural Resources and Environmental Monitoring Analysis
CEM	Center for Environmental Monitoring
CFR	Code of Federal Regulations
CH_4	Methane
CLEM	Central Laboratory of Environment and Metrology
CO	Carbon monoxide
CO_2	Carbon dioxide
CPCB	Central Pollution Control Board
DAQI	Daily Air Quality Index
DOE	Department of Environment
DONRE	Department of Natural Resources and Environment
DPCC	Delhi Pollution Control Committee
EMB	Environmental Management Bureau
EPA	Environmental Protection Agency
EPB	Environmental Protection Bureau
EPD	Environmental Protection Department
EU	European Union
FTI	Fu Tak Iam Foundation
FRM	Federal Reference Method
GBD	Global Burden of Disease
GHGs	greenhouse gases
GIS	Geographical Information System
HEI	Hedley Environmental Index
HFCs	Hydrofluorocarbons
Hg	Mercury
HKAQO	Hong Kong Air Quality Objectives
IND	India
INO	Indonesia
MEP	Ministry of Environmental Protection
MOE	Ministry of Environment
MON	Mongolia
MONRE	Ministry of Natural Resources and Environment
N^2O	Nitrous oxide
NAMEM	National Agency for Meteorology and Environment Monitoring

NAPS	National Air Pollution Surveillance
NAPSQAQC	National Air Pollution Surveillance Network Quality Assurance and Quality Control Guidelines
NEA	National Environment Agency
NEP	Nepal
NGOs	Non-Government Organization
Ni	Nickel
NILU	Norwegian Institute for Air Research
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxide
O_3	Ozone
PAHs	Polyaromatic Hydrocarbons
PAMS	Photochemical Assessment Monitoring Stations
PCD	Pollution Control Department
PFCs	Perfluorocarbons
PHI	Philippines
PM	Particulate Matter
PM_{10}	particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter
$PM_{2.5}$	particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 2.5 µm aerodynamic diameter
PRC	People's Republic of China
PSI	Pollution Standard Index
QA and QC	Quality Assurance and Quality Control
ROK	Republic of Korea
RSP	Respirable Suspended Particulates
SAR	Special Administrative Region
SEI	Stockholm Environment Institute
SEPB	Shanghai Environmental Protection Bureau
SEMC	Shanghai Environmental Monitoring Center
SF_6	Sulfur hexafluoride
SIDA	Swedish International Development Cooperation Agency
SIN	Singapore
SO_2	Sulfur dioxide
SOPs	Standard Operating Procedures
SPM	Suspended Particulate Matter
SRI	Sri Lanka
TEOM	Tapered Element Oscillating Microbalance
THA	Thailand
TSP	Total Suspended Particulates
USAID	United States Agency for International Development
USD	United States dollar
USEPA	United States Environmental Protection Agency
VEA	Viet Nam Environment Administration
VET	Vehicle Emission Testing
VIE	Viet Nam
VOCs	Volatile Organic Compounds
WHO	World Health Organization

ACKNOWLEDGEMENTS

The Asian Development Bank (ADB) and Clean Air Asia carried out Air Quality Interventions: Improving Air Quality Monitoring Systems in Asian Cities project (Sub-Project of RETA 6422: Mainstreaming Environment for Poverty Reduction) which focuses on improving AQ monitoring systems in the region and enhancing technical collaboration among Asian cities. The Sub-Project supported the assessment of air quality data in Asian cities, baseline survey on the status of air quality monitoring in Asian cities, detailed air quality monitoring systems assessment in selected cities and identification of twining opportunities. This publication, the Good Practice Guidance for AQ Monitoring in Asian cities, is one of the outputs of this work.

This was prepared by Clean Air Asia and Hong Kong Polytechnic University team led by May Ajero, Maria Katherina Patdu, Jairus Josol, and Cherine Capadocia from Clean Air Asia and Wing-Tat Hung and Shun-Cheng Lee from Hong Kong Polytechnic University. Substantial contributions were made by Vijay Joshi, Project Officer for this work from the Asian Development Bank, and Dieter Schwela from the Stockholm Environment Institute.

The authors woud like to extend special thanks to the following individuals who provided data, input, and comments for this report:

- Clean Air Asia: Wei Wan, Mariel Rodriguez, Eryn Gayle de Leon, Mylene Cayetano, and Parthaa Bosu
- Bangladesh: Abdul Jalil, Md. Abdul Jalil, Md. Masud Rana, S.R. Hayat, and Md. G. Saroar from Department of Environment, and Swapan Kumar Biswas from Department of Environment
- PR China: Jackie Fu from Shanghai Environmental Monitoring Center
- Taipei, China: Ching-Ming Chan from Environmental Protection Administration, and Wen-Jiuan Wei from Environmental Protection Agency
- India: Jagdish Kumar Bassin from National Environmental Engineering Research Institute, Mohan George from Delhi Pollution Control Committee, and Rajesh Rajaran from Institute for Financial Management and Research
- Indonesia: Ahmad Safrudin from KPBB, Amelia Rachmatunisa from Environment Agency-DKI Jakarta, and Fitri Harwati from Ministry of Environment
- Republic of Korea: Joongseop Yun from Research Institute of Public Health and Jun Bok Lee from Research Institute of Public Health and Environment
- Malaysia: Mohd Famey Yusoff from Department of Environment and Noor Zaitun Yahaya from University Malaysia Terengganu
- Mongolia: Baldorj Barkhasragchaa from Central Laboratory of Environment Metrology, Dashdondog Batdorj from Institute of Meteorology, Hydrology, and Environment, Enkhmaa Sarangerel and Gerelmaa Dashnyam from National Agency for Meteorology and Environment Monitoring, Sereeter Lodoysamba from National University of Mongolia, and Shagdar Nyamdavaa from National Air Quality Professional Office
- Nepal: Shankar Prasad Adhikari from Ministry of Environment Science and Technology
- Philippines: Dolores Velasquez and Jean Rosete from Environmental Management Bureau, Department of Environment and Natural Resources

- Singapore: Lee San Tay, Suat Hoon Soh, Tay Hee Meng, Shahrum Sulaiman, and Indrani Rajaram from National Environment Agency

- Sri Lanka: RNR Jayarathne from Central Environment Agency

- Thailand: Patchawaradee Suwanathada, Nittaya Chaisa-ard, Ittipol Paw-Armart, Vanisa Surapipith, & Amornphat Tadsanaprasittipol from the Air Quality and Noise Management Bureau, Pollution Control Department, Ministry of Natural Resources and Environment, and Surasit Insorn from Kinetics Corporation Ltd.

- Vietnam: Hoang Duong Tung from Vietnam Environment Administration, Ngo Thanh Duc, Nguyen Duy Binh, Nguyen Thanh Huy, and Le Sanh Quoc Tuan from the Center for Environment Monitoring and Analysis, Ho Chi Minh City Environmental Protection Agency, Nguyen Dang Khoi, Le Van Duc, Dang Thanh Tung, Nguyen Thi Thu Hien, Ho Thi My Dung, Nguyen Tien Nam, and Nguyen Thi Nghia from Center for Environmental and Natural Resources Monitoring and Analysis, Nguyen Dinh Tuan, Le Hoang Nghiem, and Hanh Pham from Ho Chi Minh City University for Natural Resources and Environment, and Nguyen Van Thuy and Pham Thi Vuong Linh from Center for Environmental Monitoring

- Bjarne Sivertsen from Norwegian Institute for Air Research, Judy Chow and John Watson from Desert Research Institute, USA

ABOUT THIS GUIDEBOOK

A majority of people living in Asian cities are exposed to unhealthy levels of air pollution every day. Seven out of 10 cities in developing Asian countries have unhealthy levels of air pollution, when measured as annual levels of particulate matter with size range of not greater than 10 microns (PM10) (Clean Air Asia 2011). In order to better manage air pollution, air quality (AQ) levels must be measured using appropriate AQ monitoring systems. While data availability has increased in the region, there are still several issues on AQ monitoring.

To further increase availability and scientific vigor of AQ data in Asian cities, the Asian Development Bank (ADB) and Clean Air Asia, carried out Air Quality Interventions: Improving Air Quality Monitoring Systems in Asian Cities (Sub-Project of RETA 6422: Mainstreaming Environment for Poverty Reduction) which focuses on improving AQ monitoring systems in the region and enhancing technical collaboration among Asian cities. As part of this work, the team

- Assessed AQ data (PM10, SO2 and NO2) in 273 Asian cities using the Air Pollution and Health Index of the Clean Air Scorecard Tool. These results were used as input in shortlisting cities to be included for the detailed assessment of air quality monitoring systems

- Conducted a baseline survey of air quality monitoring systems in 69 Asian cities (from 17 countries) covering (City Details; Air Quality Monitoring System; Monitoring Station Details; and Data Reporting)

- Reviewed several international guidelines on air quality monitoring and identified five essential characteristics of a good monitoring system

- Conducted a detailed assessment of air quality monitoring systems in eleven Asian cities (Bandung (Indonesia), Bangkok (Thailand), Delhi (India), Hanoi (Viet Nam), Ho Chi Minh City (Viet Nam), Jakarta (Indonesia), Rayong (Thailand), Seoul (Republic of Korea), Singapore (Singapore), Surabaya (Indonesia), and Ulaanbaatar (Mongolia) based on these five essential characteristics

- Developed initial criteria/considerations for twinning arrangements on air quality monitoring and identified potential twinning opportunities

- Organized a pre-event on improving air quality monitoring systems in Asia as part of the 2012 Better Air Quality Conference in Hong Kong SAR to discuss status of AQ monitoring in Asia, as well as the technical challenges, sustainable management and financing of AQ monitoring systems, and capacity development of AQ monitoring. This was attended by 48 participants, mostly AQ monitoring practitioners from national and city agencies representing 13 countries in Asia. There were also several international experts on AQ monitoring from Asia, US and Europe and representatives from development agencies and private sector.

The *Good Practice Guidance for AQ Monitoring in Asian cities* is based on the results of these key activities. This guide aims to provide a description of good practices for air quality monitoring systems based on essential characteristics of a good air quality monitoring system and build on lessons learned from the experience in Asian countries and cities. It evaluates how the monitoring systems in Asian cities compare against these guidelines and identifies challenges in meeting them. The practices of some cities that have made significant progress in advancing their monitoring systems are also highlighted.

Five essential characteristics of a good monitoring system

From this work, five essential characteristics of a good monitoring system have been identified and developed. This includes:

1. Plan and establish a monitoring network according to the monitoring objectives and is representative of actual air quality conditions
2. Proper implementation of QA and QC procedures
3. Sustainable operation of the air quality monitoring network
4. Effective communication of air quality information to the public
5. Effective communication of air quality information to policy and decision-makers

The following table provides an overview of the key elements for each of the five essential characteristics within the Good Practice Guide.

1 - Plan and establish a monitoring network according to the monitoring objectives and is representative of actual air quality conditions
✓ Define the purpose of the monitoring system by setting objectives. This is very crucial because it is the basis for deciding the size of the monitoring network, location of sampling stations, sampling durations and frequencies, and the resources and manpower needed.
✓ Identifying what pollutants to monitor is important in the planning process. To do this, a short-term baseline air quality monitoring study may be conducted. Prevailing exposure levels, technical feasibility, source control measures, abatement strategies, and social, economic, and cultural conditions may also be considered. In general, pollutants for which standards or guideline values have been established are measured first. Routine air quality monitoring activities in developing Asian cities may primarily focus on criteria pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3 and CO), but monitoring for research purposes in these cities may expand to other pollutants (VOCs, PAH, toxics, etc.). For Asian cities with more resources, source apportionment, toxicity analysis on particles may also follow.
✓ Determine the size of the monitoring network by considering, primarily, the monitoring objectives, and also the resources available, distribution of pollutant sources, local meteorological conditions, and topography. The minimum number of stations may be decided based on population, pollution levels, and type of pollutant/s monitored. Areas with complicated terrain and many heavy industrial sites may require more stations. Modelling may be conducted to validate the ideal number of monitoring stations.
✓ Determine the location of the monitoring stations only after the size of the network has been set. Also consider logistics, security, and availability of necessary infrastructure to maintain and operate the sites.
✓ As Asia undergoes rapid urban development, it is recommended to periodically conduct reviewof site classification of the monitoring sites to ensure that stations are still representative for monitoring objective.
✓ Consider in-situ characteristics such as sampling probe height, potential restrictions to airflow, and possible sources of interference. Probe height may depend on the pollutant being monitored and scale the station represents; however, the instrumvent should be ideally kept at a height of within breathing zone (1.5 m) until 8-10 m above ground and free from any obstructions.

- Define sampling duration should be based also on monitoring objectives. Short-range sampling is for determining peak concentration levels or pollution episodes while long-term sampling is more suited for observing trends and impacts of management strategies. Short-range sampling usually makes use of automatic and remote systems, while long-term sampling could be more cost-effective with passive and active samplers.
- Identify sampling frequency by referring to statistically generated guidelines based on the defined total sampling period; however, this should be increased when there are significant concentrations of gaseous pollutants and/or SPM (TSP, PM10, and PM2.5). For moderately polluted regions, intermittent random sampling or bi-weekly monitoring will suffice. The type of pollutants monitored will also affect the frequency of sampling.

2 - Proper implementation of QA&QC procedures

- Develop protocols and methods for operating a monitoring network by setting the data quality objectives, specifying the measurement methods, and defining the criteria for selecting the equipment and sampling sites.
- Determine whether the guidelines set are being followed. Perform site visits and equipment inspections to ensure that proper operating procedures and calibration guidelines are complied with.
- In case the guidelines are not followed, necessary corrective actions should be immediately implemented. Process should be properly documented in order to track and identify the source of errors and to replicate the procedure to yield accurate data.
- Ensure that personnel training and technical support are provided to guarantee that the guidelines listed are being implemented properly

3 - Sustainable operation of the air quality monitoring network

- Support of the entire monitoring network should be consistent and continuous for it to be sustainable. Support should not be limited to the provision of budget but should extend to equipment operation and maintenance, data transmission, and data analysis. Ample attention should be given to personnel development.
- Sufficient budget should be appropriated not only to capital cost of procurement but also for equipment maintenance, purchase of consumables, and for a replacement plan (every 8-10 years).
- Consider external sources of resources if the existing financial mechanism does not suffice. Alternative monetary sources may include grants and loans from international institutions, tax-generated subsidy, proprietary innovative technologies, private sector support, and regional centers of excellence.
- Consider outsourcing of certain components of the monitoring system operation and maintenance. However, it is important to set-up additional auditing processes either internally or externally to ensure proper implementation by contractors.

4 - Effective communication of air quality information to the public

- ✓ Disseminate information by utilizing a combination of various platforms such as published (printed) reports, brochures, papers, print media (newspapers and magazines), broadcast media (television and radio), digital properties (websites, online databases, email, or mobile), and public display screens, booths, and information boards. Consider utilizing social networking to make information easier and faster to acquire and proliferate.
- ✓ Regularly communicate air pollution status, as advised by reporting frequency guidelines set by several regulatory commissions. If possible, add forecasts to real-time reporting of air quality information
- ✓ Communicate information in a timely and straightforward manner. Develop air quality (and similar) indexes to present information to the public in a simplified form, rather than as concentrations.
- ✓ Enhance indexes with other data visualization tools such as GIS to illustrate the spatial variation of air quality and distribution of air pollutants. Other creative ways of presenting information to engage public interest may be used as well.

5 - Effective communication of air quality information to policymakers

- ✓ Present data in a simple and concise manner, making use of policy briefs, summary tables, visual presentations, interpretation of information, pie charts and maps, satellite imagery, and the like. National air quality status reports can be an effective tool in communicating 1) the extent of air pollution, 2) an analysis of the state of pollution and pollution trends, 3) identification of critical areas or projects in need of closer monitoring and support, 4) concrete recommendations to the government in improving air quality management, and 5) identification of relevant information on the contribution of industries to air pollution
- ✓ Provide concrete interventions or recommendations and the trade-offs involved in pursuing a certain plan of action. Relate the problem with other development challenges like climate change, energy use and security, and transportation.

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

A majority of people living in Asian cities are exposed to unhealthy levels of air pollution every day. Seven out of 10 cities in developing Asian countries have unhealthy levels of air pollution, when measured as annual levels of PM10 (Clean Air Asia, 2011). Recent estimates from the 2010 Global Burden of Disease (GBD) found that outdoor air pollution is a much more significant public health risk than previously known–contributing annually to 2.1 million premature deaths in Asia (Lim, S., et al., 2012). For the first time, outdoor air pollution is among the top 10 risks worldwide and among the top five or six risks in the developing countries of Asia. More people are exposed to air pollution as hundreds of millions of people will be added to Asian cities in the next decades. Over 50% of the population now lives in cities. Over the next 30 years, another 1.1 billion people are expected to be living in cities (ADB, 2010). In 2010, 12 megacities are in Asia, and by 2025, it is expected that 21 of the 37 megacities in the world will be in this region.

In order to better manage air pollution, air quality (AQ) levels must be measured using appropriate AQ monitoring systems. Starting with only 20 cities in 2003, Clean Air Asia has now compiled information on AQ and pollutant levels from over 400 Asian cities, the largest among similar databases in Asia.

While data availability has increased in the region, there are still several issues on AQ monitoring. First, monitoring in many cities in developing Asia has a limited scope – operating only a few stations which cover only a few of criteria pollutants. Second, data quality remains a concern with limited technical capacity of personnel handling data, unclear monitoring and siting guidelines and quality assurance (QA) and quality control (QC) procedures. Another issue is the lack of linkages between the monitoring data and air pollution control measures and policies. Finally, sustainability of the monitoring system is a continuous challenge especially with budget constraints.

Significant investments in AQ monitoring systems have been made in the past. Unfortunately, not all of these have been sustained. This was probably because the establishment heavily relied on foreign assistance and expertise, several of which ended after projects were completed.

Sustaining reliable AQ monitoring systems can be achieved as successful cases in selected Asian cities have shown. Asian cities looking to establish or maintain their AQ monitoring systems can learn from Asian examples – whose financial, policy, institutional systems may be similar, in addition to comparable air pollution issues.

This *Good Practice Guidance for AQ Monitoring in Asian cities* provides a information on good practices for air quality monitoring systems based on five essential characteristics and builds on lessons learned from the experience in Asian countries and cities.

1.2 ABOUT THE PROJECT

This *Good Practice Guidance for AQ Monitoring in Asian cities* was developed based on the results of the **Air Quality Interventions: Improving Air Quality Monitoring Systems in Asian Cities** project (Sub-project of RETA 6422: Mainstreaming Environment in Poverty Reduction) which focuses on improving AQ monitoring systems in the region and enhancing technical collaboration among Asian cities.[1] The objective of the project is to identify the cities that have achieved significant improvement in air quality and enhance opportunities for south-south learning by twinning. The intended outcome of this project is to identify interventions to improve air quality data and enhance technical collaboration among Asian cities by developing improved understanding of the current status, quality, and best practices in air quality monitoring.

The long term impact to which the project contributes is improved air quality in developing Asian cities due to better policies that are informed by publicly available, reliable and meaningful data from air quality monitoring. The short term impact is better awareness and access to know how to improve air quality monitoring systems and interpretation of air quality data.

As part of this work, the team

- Assessed AQ data (PM_{10}, SO_2 and NO_2) in 273 Asian cities using the Air Pollution and Health Index of the Clean Air Scorecard Tool. These results were used as input in shortlisting cities to be included for the detailed assessment of air quality monitoring systems

- Conducted a baseline survey of air quality monitoring systems in 69 Asian cities (from 17 countries) covering (City Details; Air Quality Monitoring System; Monitoring Station Details; and Data Reporting)

- Reviewed several international guidelines on air quality monitoring and identified five essential characteristics of a good monitoring system

- Conducted a detailed assessment of air quality monitoring systems in eleven Asian cities Bandung (Indonesia), Bangkok (Thailand), Delhi (India), Hanoi (Viet Nam), Ho Chi Minh City (Viet Nam), Jakarta (Indonesia), Rayong (Thailand), Seoul (Republic of Korea), Singapore (Singapore), Surabaya (Indonesia), and Ulaanbaatar (Mongolia) based on these five essential characteristics

- Developed initial criteria/considerations for twinning arrangements on air quality monitoring and identified potential twinning opportunities

- Organized a pre-event on improving air quality monitoring systems in Asia as part of the 2012 Better Air Quality Conference in Hong Kong SAR to discuss status of AQ monitoring in Asia, as well as the technical challenges, sustainable management and financing of AQ monitoring systems, and capacity development of AQ monitoring. This was attended by 48 participants, mostly AQ monitoring practitioners from national and city agencies representing 13 countries in Asia. There were also several international experts on AQ monitoring from Asia, US and Europe and representatives from development agencies and private sector.

The *Good Practice Guidance for AQ Monitoring in Asian cities* summarizes the key lessons learned from this project. This guide aims to provide a description of good practices for air quality monitoring systems based on essential characteristics of a good air quality monitoring system and build on lessons learned from the experience in Asian countries and cities.It evaluates how the monitoring systems in Asian cities compare against these guidelines and identifies challenges in meeting them. The practices of some cities that have made progress in advancing their monitoring systems are also highlighted.

---

[1] For more information, visit: http://cleanairinitiative.org/portal/aqinterventions

1.3 TARGET AUDIENCE

The primary audiences for this guide are the technical staff and management of national and local governments and other institutions that operate (or will operate) an air quality monitoring system. It may also be useful to policymakers to determine effective mechanisms to finance air quality monitoring systems within their jurisdictions.

1.4 REPORT STRUCTURE

This guidebook is structured around the five essential characteristics for AQ monitoring

- Section 2.2 Plan and establish an AQ monitoring network
- Section 2.3 Proper implementation of QA and QC procedures
- Section 2.4 Sustainable operation of the AQ monitoring network
- Section 2.5 Effective communication of AQ information to the public
- Section 2.6 Effective communication of AQ information to policy and decision-makers

Each Section contains:

- International Good Practices
- Status and Challenges in Asia
- Case Studies of Good Practices in Asia

2. GOOD PRACTICE IN AQ MONITORING SYSTEMS

2.1 BACKGROUND

An effective air quality management system requires a dynamic and extensive understanding of both the sources and outcomes of air pollution. This is important towards the end goal of achieving and/or maintaining a level of air quality that protects human health and the environment (Stockholm Environment Institute (SEI) & Korea Environment Institute (KEI, 2004). Even as air quality monitoring is just one component in the overall air quality management framework (along with other processes such as source apportionment and emissions inventories, dispersion modelling, health and environmental impact assessment, land-use planning, cost-benefit analysis, control options and actions, legislation and implementation) (Haq & Schwela, 2008), it helps define the nature and status of air quality, which then guides the development of an effective AQM strategy and other relevant applications (Sivertsen, 2002; Schwela, 2010).

In most instances, the people responsible for monitoring air quality are different from those responsible for formulating policies that address the problem, and from the public whose well-being and assets are affected by the deterioration of air quality. For this reason, design of monitoring systems need to go beyond data collection. They must also ensure that air quality information is communicated in a manner that is easily understood by policymakers, public, and other relevant stakeholders. This is particularly important in developing countries in Asia.

Air pollutant levels at a certain location are determined by a combination of processes, including the intensity of local source emissions, the atmospheric capacity to dilute emission, the natural removal processes, the physical and chemical transformation of pollutants, and the amount transported from upwind regions (SEI, 2008). Owing to the complex nature of air pollution and its drivers, the process of air quality monitoring is dynamic. To be effective, air quality montoring systems need to be periodically reviewed and improvied to ensure that it is responsive to these factors.

This section describes the essential characteristics of aneffective monitoring system (Table 1), based on international guidelines. It evaluates how the monitoring systems in Asian cities compare against these guidelines and identifies challenges in meeting them. The practices of some cities that have made significant progress in advancing their monitoring systems are also highlighted. It must be noted, however, that the assessment of Asian cities is not meant to be exhaustive, but it is intended as a starting point for the discussion on the state of monitoring systems in Asian cities. It is also not meant to replicate international guidelines, only to highlight key guidance areas. Readers are directed to the complete references for each section for detailed information. It is hoped that this document will serve as a quick guide for cities in Asia in designing or improving their own monitoring systems.

Table 1. Essential characteristics of aneffective monitoring system

Essential characteristics
1. Properly plan and implement an AQ monitoring network to a compatible international standard 2. Proper implementation of QA&QC procedures 3. Sustainable operation of the air quality monitoring network 4. Effective communication of air quality information to the public 5. Effective communication of air quality information to policy and decision-makers

2.2 CHARACTERISTIC 1: PLAN AND ESTABLISH A MONITORING NETWORKTHAT MEETS MONITORING OBJECTIVES AND IS REPRESENTATIVE OF ACTUAL AIR QUALITY CONDITIONS

2.2.1 INTERNATIONAL GOOD PRACTICES

Planning is important because it ensures that the design of the monitoring system is technically sound. It also enables identification of management strategies that maximize the use of resources in achieving the air quality goals. This is particularly relevant in developing countries whose resources are often limited.

Defining the purpose for establishing a monitoring system is the first step in planning. This is very crucial because it is the basis for deciding the size of the monitoring network, location of sampling stations, sampling durations and frequencies, and the resources and manpower needed. Listed in Table 2 are the commonly-cited objectives of a monitoring network (Analysis and Air Quality Division, 2004; Schwela, 2010; Sivertsen, 2002; UN ECE, 2009; US EPA, 1994, 2013a). For simplicity, they are grouped according to the three broad types of monitoring stipulated by the United States Environmental Protection Agency (USEPA). Some of the specific objectives are not exclusive to one category.

Air quality monitoring fundamentally serves three objectives: for timely public reporting, compliance and for research purposes. Identifying the air quality monitoring objective is important as this decides the size of the monitoring network and therefore, the resources and manpower needed.

Table 2. Common objectives for conducting air quality monitoring

Basic Objectives	Specific Objectives
Timely public reporting	- Assess short-term pollution levels -Develop an air quality index (or other tools for data communication) - Forecasting
Compliance	- Determine compliance levels with standards - Observe pollution trends - Formulate pollution control strategies - Evaluate the effectiveness of pollution control strategies - Support national and international agreements and initiatives
Research	- Assess impacts to different groups of populations - Assess impacts to ecosystems and assets - Validate models - Discover new contaminants

Source: US EPA, 2013a.

This guidance primarily focuses on timely public reporting and compliance. For timely public reporting, faster response time of the monitoring stations is necessary, while for compliance purposes, this may be depends on national air quality standards. Once the monitoring objectives is identified, the following will be defined

- Pollutants to monitor
- Size and location of monitoring stations
- Sampling frequency and duration
- Monitoring equipment

Pollutants to monitor

Identifying what pollutants to monitor is important in the planning process. Measuring all possible air pollutants is costly and impractical (Schwela, 2010). It is, therefore, ideal to conduct a short-term study to screen the pollutants that are relevant to the area. In general, pollutants for which standards or guideline values have been established are measured first. Shown in Table 3 are the criteria and recommended pollutants of concern for various international organizations and monitoring agencies. Most of them share a common set of criteria pollutants which could be useful for regional comparisons. The diversity in the monitored auxiliary pollutants is simply a reflection of different priorities and concerns specific to the organization or monitoring agency.

In addition to identifying a set of priority pollutants to monitor, the national/city-level monitoring agencies and international organizations establish their own set of allowable pollutant levels.[2]

Table 3. Set of pollutants that are commonly monitored

Organization	Criteria Pollutants								Recommended Pollutants
	PM_{10}	$PM_{2.5}$	SO_2	O_3	NO_2	CO	Pb	Benzene	
US EPA	✓	✓	✓	✓	✓	✓	✓		O_3 precursors (NOx, VOCs)
WHO	✓	✓	✓	✓	✓	✓	✓		Carcinogenic compounds
AAQD (CAN)	✓	✓	✓	✓	✓	✓			PAHs, VOCs, acid aerosols
EU	✓		✓	✓	✓	✓	✓	✓	$PM_{2.5}$, PAHs, As, Cd, Ni, Hg

Note: O3 = Ozone; NOx = Nitrogen oxides; VOCs = Volatile organic compounds; PAHs = Polycyclic aromatic hydrocarbons; As = Arsenic; Cd = Cadmium; Ni = Nickel; SO2 = Sulfur dioxide; NO2 = Nitrogen dioxide; CO = Carbon monoxide; Hg = Mercury; Pb = Lead; PM2.5 = Particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 μm aerodynamic diameter; PM10 = particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter; US EPA = United States Environmental Protection Agency; WHO = World Health Organization; AAQD (CAN) = Ambient Air Quality Directives (Canada); EU = European Union; PM2.5 is regulated in Directive 2008/50/EC. Other recommended pollutants are noted in Directive 2004/107/EC
Source: US EPA 40 CFR Part 58, 1999a; WHO,2005; Environment Canada, 2004; EU Directive 2004/107/EC and 2008/50/EC.

Size and location of monitoring stations

Another important consideration in the design of monitoring systems is the size and location of the monitoring stations. This is to ensure that the measurements taken are adequate and representative of the air quality conditions of the area.

The size of monitoring networks primarily depends on the reasons for monitoring. But aside from the stated objectives, sizing also involves tradeoffs on the resources available, distribution of pollutant sources, local meteorological conditions and topography that affect the dispersion of pollutants. In most guidelines, while values and categories vary, the minimum number of monitoring stations is determined according to population and pollution levels. As an illustration, Table 4 compares the prescribed minimum number of monitoring stations for PM10 for USEPA and EU. Both guidelines recommend more monitoring stations in areas with higher levels of pollution. The minimum number of stations is also dependent on the type of pollutant monitored (Table 5).

While international guidelines provide the basic criteria for the minimum required number of monitoring stations, the Joint Research Centreand the working group on 'Siting Criteria, classification and representativeness of air quality monitoring stations (SCREAM)' (2013) caution that that these recommended minimum number of monitoring sites may be insufficient for areas with complex terrain or mixed emissions distribution. The USEPA

[2] It is noted that the air quality guidelines set by the World Health Organization (WHO) and developed countries are generally more stringent than those of their developing counterparts. It is noted that WHO guidelines are more stringent than national standards as these are primarily based on health impacts. The WHO guidelines are not enforceable unless they are adopted by countries as standards (SEI, 2008). In adopting legally binding standards, other considerations such as prevailing exposure levels, technical feasibility, source control measures, abatement strategies, as well as social, economic and cultural conditions must be taken into consideration (SEI, 2008).

and the EU guidelines (Table 4) for minimum number of AQ monitoring stations are generally applicable to simple terrain and emission sources. Number of stations required may have to increase in complex terrain and emission sources. On the other hand, for less developed areas where it is unlikely to have complicated emission sources, lesser stations are needed.

Table 4. Prescribed number of PM10 sampling points recommended by US EPA and EU according to pollution levels and population agglomeration

US EPA[1]			EU[2]		
Population (thousands)	Levels of Pollution		Population (thousands)	Levels of Pollution	
	Low	High		Low	High
100-250	0	1-2	0-249	1	2
250-500	0-1	3-4	250-499	2	3
500-1,000	1-2	4-8	500-999	2	3-4
> 1,000	2-4	6-10	1,000-1,499	3	6
			1,500-1,999	3	7
			2,000-2,749	4	8
			2,750-3,749	4	10
			3,750-4,749	6	11
			4,750-5,999	6	13
			≥6,000	7	15

Note: US EPA = United States Environmental Protection Agency; EU = European Union
[1]As stated in the US EPA 40 CFR Part 58 Appendix D "Network Design Criteria," "Low" refers to areas whose ambient PM10 concentrations are below 80% of the National Ambient Air Quality Standard (NAAQS), whereas "High" refers to areas whose ambient PM10 concentrations exceed the NAAQS by 20% or more.
[2]As stated in EU Directive 2008/50/EC, "Low" refers to maximum concentrations between upper and lower assessment threshold, whereas "High" refers to maximum concentrations exceed the upper assessment threshold. For PM lower assessment threshold is 50% of limit value, upper assessment threshold is 70% of limit value. For 24-hour PM10 the number of permissible exceedances is also important.
Note: The US EPA gives a range of sampling points while the EU provides a minimum number. It is noted that a sampling point is not necessarily a station.Directive 2008/50/EC distinguishes between the term sampling point and station. Monitoring by passive samplers usually is not characterized as monitoring at a station. A station is usually considered as a site where some container is used for monitoring gaseous and particulate concentrations via analyzers.

Table 5. Comparison on the number of sampling points for PM and other pollutants for EU

Population (thousands)	High Pollution Levels		Low Pollution Levels	
	Others[1]	PM	Others	PM
0-250	1	2	1	1
250-499	2	3	1	2
500-999	2-3	3-4	1	2
>1,000	4	6	2	3
1,500-1,999	5	7	2	3
2,000-2,749	6	8	3	4
2,750-3,749	7	10	3	4
3,750-4,749	8	11	3	6
4,750-5,999	9	13	4	6
≥6,000	10	15	4	7

[1]Refers to stations that monitor pollutants other than PM (i.e. SO_2, NO_2, Pb, CO)
Note: PM = Particulate matter; SO_2 = Sulfur dioxide; NO_2 = Nitrogen dioxide; Pb = Lead; CO = Carbon monoxide
Source: EU Directive 2008/50/EC and US EPA 40 CFR Part 58, 1999a.

It is noted that air quality guideline values in the US and EU are more stringent than in Asia. For most Asian cities, pollution levels may be considered as 'high' according to these guidelines. As such, it is recommended to compare number of monitoring stations for Asian cities based on 'high' pollution levels scenario (Table 4 and Table 5).

For Asian cities with relative flat terrain and no heavy industrial areas, the number of AQ monitoring sites required can be minimal. However, for cities with complicated terrain and many heavy industrial areas, the number of AQ monitoring sites should be close to high side as presented in Table 4. Additional assessments or modeling with basic emissions inventory is recommended to determine whether the recommended minimum number of monitoring sites appropriately represent the area or not.

The ambient air quality standards for criteria pollutants in a jurisdiction usually set the basic pollutants to be monitored. The underlying principle is to consider key pollutants that are ubiquitous in urban air, recognized as potential health risk, and those commonly regulated at a national or international level.

It is also noted that the pollutants of concern and pollution tendency change as an area develops. A monitoring plan, therefore, must be flexible to respond to such changes. In the United States, for example, the number of monitoring sites increased as industrialization and urbanization progressed. The pollutants monitored at the sites also shifted from predominantly TSP, NO_2, and SO_2, to PM_{10}, $PM_{2.5}$ and O_3 (US EPA, 2005). These changes also highlight the need to periodically review air quality standards and monitoring system to ensure that it appropriately represents the air pollution issue based on recent scientific understanding. In the US, the EPA is required to to evaluate the National Ambient Air Quality Standards every five years to determine whether it is adequately protective of human health and the environment.[3]

Determining the specific location of a monitoring site follows after deciding on the size of the monitoring network. This ensures that potential biases in the samples are avoided. Sampling locations usually depend on the overall monitoring objectives, sources and emissions, meteorology, topography, existing a priori knowledge on air pollution, input from dispersion modelling and other inputs such as demographic and land use information. These are often grouped as urban, sub-urban, and rural. Urban and sub-urban is further classified into background, ambient, traffic, and industrial.

Specific in-situ characteristics must also be considered. They include, among others, sampling probe height, potential restrictions to airflow, and possible sources of interference. Recommended probe height may depend on the pollutant being monitored and scale[4] the station represents; however it is ideal to keep the instrument at a height of within breathing zone (1.5 m) until 8-10 m above ground and free from any obstructions (such as trees, buildings, etc.) that may constrict air flow. Table 6 shows examples of site-specific characteristics that are taken into account in determining the probe height of potential monitoring stations for particulate matter. The height of the probe also depends on the type of stations. For background or ambient stations, the height should be higher to sample air quality above the mixing zone, typically above 5 m. For monitoring roadside traffic air pollution, the height of the probe should be closer to the ground, typically within 5 meters.

For monitoring particulate matter (PM), SO_2, O_3, and PAH the distance of the sampling site from obstacles such as a building must be at least twice the height of the obstacle and unrestricted airflow must exist 270 degrees around the sampler. For curbside monitoring of PM, NO_2 and CO the distance of monitoring sites from the edge of the traffic lanes must be at least 2 m and have unrestricted air flow of at least 180 degrees (Schwela, 2010).

Logistics is a related concern in deciding where to place the monitoring sites. Security of the equipment is particularly important along with the necessary infrastructure to maintain and operate monitoring sites such as availability of space and the ability to connect to power and telephone lines. Agreement with owners of certain spaces for monitoring sites is important as well. It is often time-consuming to obtain permission to use these spaces for a station.

[3] Section 109(d)(1)) of the Clean Air Act govern the establishment, review, and revisions of the NAAQS (42 U.S.C. 7408 and 7409).
[4] Scale = maximum monitoring path length.

Table 6. In-situ characteristics for determining the probe height of particulate matter samplers

Organization	Height above ground (m)	Distance from support structure (m)	Distance from trees (m)
AAQD (CAN)	2-15	>2	>20
US EPA	2-7 for middle scale (300 m) 2-15 for other scales	>2	>10
EU	1.5 (breathing zone) to 4 until 8	Exact number not specified	Exact number not specified

Note: US EPA = United States Environmental Protection Agency; AAQD (CAN) = Ambient Air Quality Directives (Canada); EU = European Union.
Source: Environment Canada, 2004; US EPA Guidance for Network Design and Optimum Site Exposure for PM2.5 and PM10, 1997; UN ECE Guidelines for Developing National Strategies to Use Air Quality Monitoring as an Environmental Policy Tool, 2009.

When, how often, and how often to sample

Knowing when, how long, and how often to sample is also important in achieving the monitoring objectives. As an example, short-term sampling is appropriate for determining peak concentration levels or detecting short-term pollution episodes. If, however, the goal is to determine the changes in pollutant trends, or assess the impacts of management strategies, long-term sampling is necessary.

Monitoring equipment

Knowing the appropriate sampling duration is likewise important in choosing the type of monitoring system to use. Currently, there are four types of air monitoring technologies commonly used: passive (or diffusive) samplers, active samplers, automatic online analyzers, and remote sensors. A passive sampler, usually in the form of a disc or tube-shaped device, absorbs pollutants into a chemical substrate, and after a prescribed sampling period and analysis procedures, desorbs the pollutants to be subsequently calculated. Active samplers, on the contrary, require electricity to pump the air gathered through a physical or chemical collection vehicle. Both passive and active samplers require laboratory analysis. They can only produce the average pollutant concentration over the exposure period.

Automatic gas/particulate analyzers and remote sensors, meanwhile, can perform processing on the spot. Automatic analyzers collect air in chambers that detect the physical or optical properties of gas/particles and produce electric signals comparative to the concentration of the pollutant being measured. While automatic analyzers can measure a particular pollutant at a single point in space and interval in time; more complex remote sensors can provide integrated, multi-component measurements along a precise path in the atmosphere. These automatic analyzers can produce continuous rather than discrete readings of pollutant concentrations and are thus able to detect the change of pollutant concentrations over the exposure period.

Generally, high operational cost and complexity limit the application of automatic and remote systems to short-duration measurements, while passive and active samplersare commonly used for longer measurement periods covering larger areas as they are more cost-effective (Schwela, 2010). Table 7 below provides more detail on the attributes of each methodology (Schwela, 2010).

Table 7. Advantages, Cost, and Accuracy of Air Quality Monitoring Sampling Systems

Sampling	Sample Acquisition/ (Average Time)	Type of sample collection	Amount of air sampled (liters/min)	Cost (USD)	Advantages	Disadvantage	Examples
Passive	Integrating / (1-60 days) (minimum) Passive sampling is aimed to get average pollutant levels over a period of time, usually 1 to 60 days.	Manual	Depends on site (0-3lpm) The ~3 lpm is meant to be natural wind flow and can be zero.	Sampling: 10-70 Analysis: 60-100 per parameter	Low cost of capital outlay, samplers can be deployed n large numbers, useful for screening and mapping	Unproven for some pollutants, longer averaging time, may be labor intensive indeployment and post sampling analysis depending on the number of samples and location, slow data throughput, requires laboratory analysis	See examples in Quirit et al. 2006
Active	Integrating / (4-24 hrs)	Manual	Low volume (4lpm)	~4000	Low cost of capital outlay, easy to operate, effective for long term sampling Data continuity over time is good and better time resolution and better accurancy.	Labor intensive deployment and post sampling analysis, slow data throughput, requires laboratory analysis, provides daily averages only	US EPA 1999a Compendium Method IO-2.3
			Low volume (16.7 lpm)	~10,000	Easy to operate, has Federal Reference Method (FRM) approval, ideal for health-related studies		Single-event particulate matter sampler (1.e., US EPA 1999a Compendium Method IO-2.2, Cyclone and impactor-type samplers)
			High volume (40 lpm)	~20,000	Easy to operate		

Sampling	Sample Acquisition/ (Average Time)	Type of sample collection	Amount of air sampled (liters/min)	Cost (USD)	Advantages	Disadvantage	Examples
							Dome-shaped design, as explained in US EPA 1999a Compendium Method IO-2.1
		Automatic	Low (16.7 lpm)	~50,000	Easy to operate, can be left unattended for a longer period of time.		Sequential samplers, etc.
	Continuous/ (1 -60 min)	Automatic	Low (1-4 lpm)	10,000~ 50,000	Gives historical data set, has FRM approval, easy to operate, highly-resolved data		Grimm et al., 2009, US EPA 1999a Compendium Method IO-1.2-1.3
	Semi-continuous/ (30 min-1 hr)	Automatic	Low (1 – 16.7 lpm)	~100,000	Ideal for in depth chemical speciation/ profiling and analysis	Very high cost on capital outlay, needs highly-technical person to operate and analyse data	Hunter et al, 2009; Johnson K.S., et al, 2009; Kidwell C. B. and Ondov J. M., 2011; Parshintsev J., Et al., 2009

Note: lpm = liters per minute
Note: Active-integrating automatic = Active means having a pump; integrating means only one single reading over the monitoring period
Active continuous automatic = Continuous means sampling can be carried out over the entire monitoring period with a pre-set sampling time period
Active semi-continuous automatic = Semi-continuous means sampling can be discontinous owing to limitation of power supply and other restrictions during the entire monitoring time. One has to restart the monitoring equipment.
Integrating = Only one single pollutant concentration can be obtained for the entire monitoring period; there is no breakdown of concentration over time. Source: Adapted from Schwela, 2010.

Sampling frequency

Setting the appropriate sampling frequency is also essential in ensuring that enough data is collected to allow statistical analyses and, subsequently, allow insights to be drawn. This pertains to both the duration of the sampling period as well as the frequency by which the sampling is conducted. Table 8 shows the minimum sampling frequency for each sampling period.

Table 8. Sampling periods and corresponding minimum number of sampling required

Study Period/ Time Interval	Minimum number of observations	Applicable foractive sampling only
1hour average	45 consecutive observations of 1-minute duration	Continuous AQMS
8hour average	6 consecutive hourly observations	Continuous and Semi-continuous AQMS
24hour average	18 consecutive hourly observations	Continuous and Semi-continuous AQMS
Month	21 daily observations	Integrating (Active), Continuous and Semi-continuous AQMS
Year	9 monthly averages[1]	Integrating (Active), Continuous and Semi-continuous AQMS

[1]No data of two consecutive months should be missing.
Source: Schwela, 2010.

In the table above, the first column is the commonly specified (internationally) pollutant concentration periods; the second column is the minimum samples required for a statistically representative sample sizes; while the third column is the sampling methods that this sampling requirements apply to.

It is noted the above requirements is for active sampling only and not for passive sampling. Active continuous sampling is expected to capture data all the time. The minimum sampling requirement exists for the downtime (maintenance and equipment failure). The expected sample capture rate is usually over 90% as there are usually very reliable.

Further, the above requirements only reflect a statistically-generated guideline. In highly polluted areas, ambient air should be sampled at a frequency greater than the minimum when there are significant concentrations of gaseous pollutants and/or SPM (TSP, PM_{10}, and $PM_{2.5}$) (Schwela, 2010). For moderately polluted regions, intermittent random sampling or bi-weekly monitoring should suffice.

The frequency of sampling is dependent on the type of system used in monitoring,as different types of equipment would have varying capacities in terms of the rate it could carry out the sampling. Different pollutants also need different sampling frequencies.

Pollutants and particulate matter levels also vary seasonally and should be taken into account when determining frequency. Various countries and cities have their own sampling frequency conventions, as in the case of India where gaseous pollutants are sampled for 4 hours, six times in 24 hours, and particulate matter is sampled for 8 hours, three times a day. This is done twice a week to have a total of 104 observations annually (CPCB, 2003). In the Philippines, SO_2 and suspended particulate matter are sampled once every six days when using the active-manual methods. A minimum total of forty-eight sampling days each year is required (Clean Air Act, 1999).

The components listed above are not exhaustive as they are meant only as a guide in determining the essential characteristics of a good monitoring system. More information on designing monitoring networks can be found at the following:

- Air Planning and Standards, USEPA
  http://www.epa.gov/airquality/montring.html
- National Air Pollution Surveillance Program, Environment Canada
  http://www.ec.gc.ca/rnspa-naps/
- Directives for Monitoring Atmospheric Pollution, EU
  http://eur-lex.europa.eu/en/legis/latest/chap15102030.htm
- Foundation Course on Air Quality Management in Asia, SEI
  http://www.sei.se/cleanair/modules.html
  GAP Forum Air Pollution Monitoring Manual, SEI:
- http://sei-international.org/rapidc/gapforum/html/technical/monitoring/GAP_Forum_Monitoring_Manual_2010.pdf

2.2.2 STATUS AND CHALLENGES IN ASIA

An air quality monitoring survey was conducted as part of this project to gain a better understanding of the status of air quality monitoring systems in Asian cities. The survey covered 69 cities and 17 countries.[5] There were at least seven megacities[6] included in the survey, namely, Beijing, Delhi, Dhaka, Guangzhou, Manila, Mumbai, Shanghai, and Tokyo. Figure 1 illustrates the countries and cities included in the survey conducted by Clean Air Asia.

Figure 1. Map of Asia showing the countries (highlighted dark green) and the number cities which have participated in the survey

[5] Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, India, Indonesia, Japan, Lao PDR, Mongolia, Nepal, Philippines, Singapore, South Korea, Sri Lanka, Thailand and Viet Nam

[6] A **megacity** is usually defined as a metropolitan area with a total population in excess of 10 million people. (UN Department of Economic and Social Affairs, World Urbanization Prospects 2011 Revision)

Number of monitoring stations

Generally, most the cities surveyed (57%) do not have adequate number of monitoring stations relative to the guidelines stipulated by the EU Directive 2008/50/EC. (Figure 2). This observation is further emphasized when only developing countries were considered.

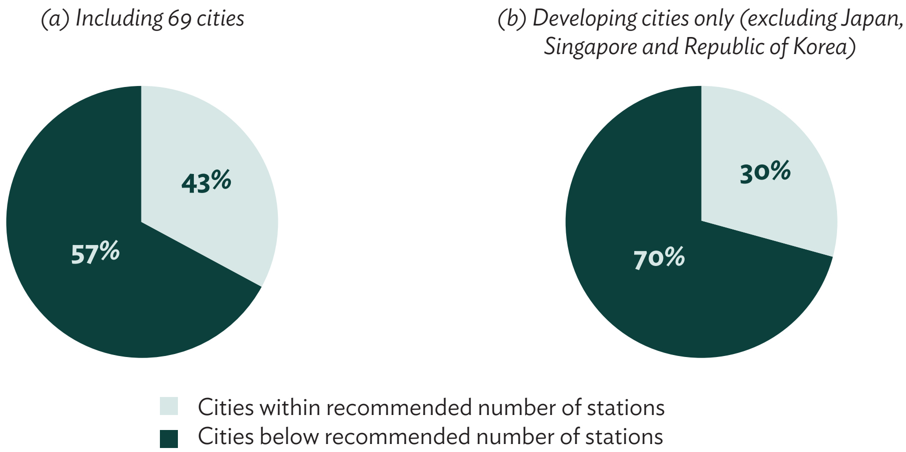


Figure 2. Percent share of cities within and below the minimum recommended number of stations

It is observed that the monitoring coverage of cities from developing countries only achieved the bare minimum, while the coverage for developed countries are more than double the prescribed number (Table 9). For example, Dhaka (Bangladesh) has only three monitoring stations for a population of 14 million whereas Chiba (Japan) has 19 monitoring stations to cover a population of 96,000.

As seen Table 9, existing monitoring systems in advanced economies in Asia significantly exceed the recommended minimum number of monitoring stations based on international guidelines. This may be because of different monitoring objectives. Other reasons for having more monitoring sites include complicated terrain, different types of sources distributed in the urban area, spectrum of emitted pollutants, among others. Developing Asian cities do not necessarily have to follow the same approach and may develop a monitoring system which would provide sufficient information within their available resources.

Table 9. Number of monitoring stations in Asian cities and their prescribed density relative to total population

Country[1]	City[2]	Population[3]	Number of sites	Prescribed minimum number of sites[4]
Developed Asia				
Japan	Shizuoka	712,340	14	4
Japan	Sagamihara	719,677	7	4
Japan	Hamamatsu	816,846	13	4
Japan	Chiba	961,749	19	4
Japan	Sendai	1,055,770	16	6
Japan	Hiroshima	1,182,613	11	6
Japan	Saitama	1,242,729	16	6
Japan	Kawasaki	1,432,374	19	6
Japan	Fukuoka	1,489,753	16	6
Japan	Nagoya	2,267,048	21	8
Singapore	Singapore	5,183,700	15	13
Republic of Korea	Seoul	10,026,000	46	15
Japan	Tokyo	13,000,000	78	15

Country[1]	City[2]	Population[3]	Number of sites	Prescribed minimum number of sites[4]
Developing Asia				
Brunei Darussalam	Bandar Seri Begawan	16,381	1	2
Bhutan	Thimphu	99,337	1	2
Thailand	Khonkaen	113,754	1	2
Thailand	Nakhon Ratchasima	116,217	1	2
Thailand	Chiang Mai	148,477	2	2
Thailand	Chonburi	180,000	3	2
Sri Lanka	Colombo	693,000	1	4
Lao PDR	Vientiane	810,000	0	4
Philippines	Cebu	838,600	2	4
Nepal	Kathmandu	1,014,570	0	6
Mongolia	Ulaanbaatar	1,184,000	12	7
Philippines	Davao	1,522,678	4	7
Cambodia	Phnom Penh	1,550,000	1	7
India	Kochi	1,592,263	7	7
India	Visakhapatnam	1,700,228	8	7
India	Indore	2,127,497	3	8
Indonesia	Bandung	2,399,494	21	8
Indonesia	Surabaya	2,768,199	4	10
India	Kanpur	2,904,192	6	10
Viet Nam	Hanoi	2,955,130	7	10
PR China	Jinan	3,581,356	20	10
India	Surat	4,438,444	3	11
PR China	Xian	4,845,821	19	13
India	Pune	4,951,375	3	13
Bangladesh	Chittagong	5,069,181	2	13
PR China	Hangzhou	5,189,275	21	13
PR China	Nanjing	5,664,951	18	13
Viet Nam	Ho Chi Minh City	6,189,423	3	15
PR China	Hong Kong SAR	7,122,190	15	15
India	Bangalore	8,275,032	9	15
Thailand	Bangkok	8,426,000	17	11
India	Chennai	8,522,504	6	15
PR China	Tianjin	8,535,265	27	15
Indonesia	Jakarta	9,769,000	14	15
PR China	Guangzhou	10,485,570	20	15
Philippines	Metro Manila	11,861,600	22	15
Bangladesh	Dhaka	15,390,900	3	15
PR China	Beijing	15,594,400	27	15
India	Mumbai	19,421,983	6	15
PR China	Shanghai	19,554,059	32	15
India	Delhi	22,653,600	13	15

[1]Cities included are limited to those with population ≥ 2 million for India, ≥ 100,000 for Thailand, and select large cities from PR China for which the number of monitoring stations can be ascertained.
[2]Number of monitoring stations for Indian cities were based on CPCB stations only; Monitoring stations for Metro Manila include stations recently set-up in 2012 and 2013 and TSP stations. This does not include the stations for restoration.
[3]Most recent available population estimates were used. Japan cities: Statistics Bureau of Japan; Singapore: Statistics Singapore; Seoul (as Seoul Metropolitan City): Statistics Korea; World Urbanization Prospects (2011): PR China cities, India cities, Philippines cities, Indonesia cities, Thimphu, Manila, Hanoi, Hong Kong SAR, Phnom Penh, Colombo, Ulaanbaatar, Vientiane, Bangkok, Bandar Seri Begawan, HCMC, Chittagong, Kathmandu; Khon Kaen: Khon Kaen Municipal Government website; Chiang Mai: City Government website; Nakhon Ratchasima: City Municipality website; Chonburi: City Government website.
[4]Taken from the EU Directive 2008/50/EC values from high concentration areas were used. This evaluation criterion is more stringent relative to the lower concentration areas of the US EPA and that of the EU.

Pollutants monitored

As previously mentioned, pollutants wherein national standards/guideline values have been established are first to be monitored. Table 10 shows the pollutant coverage of national standards/ guideline values in different countries and the pollutants monitored in the cities. It is observed that in more than half of the countries surveyed, not all pollutants with national standards are monitored by cities. For instance, Figure 3 illustrates that in national capitals, particulates (PM10, PM2.5, and TSP) are the most widely monitored pollutant – a trend that is consistent with literature (Schwela, 2010). This is closely followed by Sulfur dioxide (SO2) and Nitrogen oxides (Nitrogen dioxide and Nitrogen monoxide). Also from the same figure, it can be observed that lead (Pb) is the least monitored pollutant. This could be an indication of the relative success of the efforts to phase out leaded gasoline in Asia.

As observed internationally, countries and cities in Asia have slowly moved from monitoring TSP towards monitoring PM10 and PM2.5. This is evident by national governments establishing PM2.5 standards in recent years (See Figure 4). This is consistent with scientific research focusing on the health (and other) impacts of finer particulates. It is likely that routine air quality monitoring activities in Asian cities still focus on criteria pollutants (PM10, PM2.5, SO2, NO2, O3 and CO), but monitoring for research purposes in these cities may expand to other pollutants (VOCs, PAH, toxics, etc). For Asian cities with more resources, toxicity analysis on particles may also follow.

Table 10. Pollutants which have national standards and pollutants currently monitored at the city level

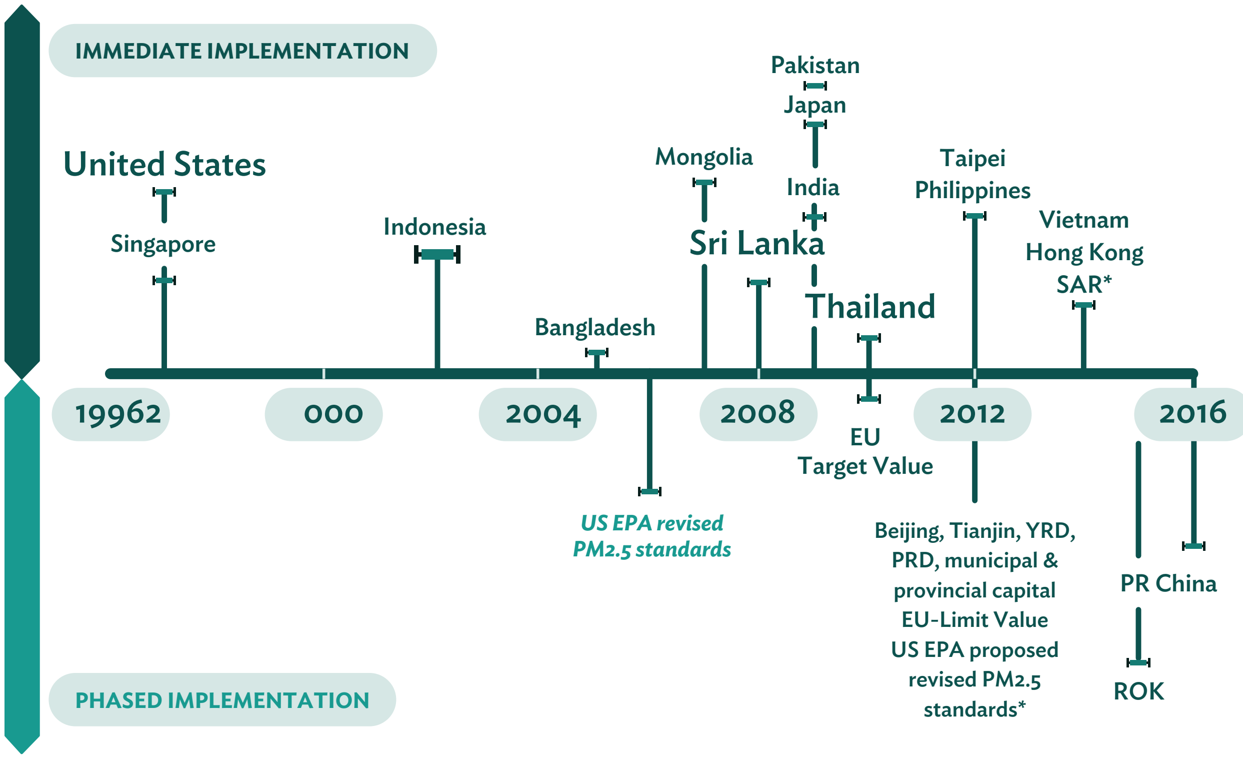
Countries and Major Cities		Pollutants							
		TSP	PM_{10}	$PM_{2.5}$	Pb	NO_2	SO_2	O_3	CO
Bhutan	With standard/GV	✓	✓			✓	✓		✓
• Thimphu	Monitored		✓				✓		
India	With standard/GV		✓	✓	✓	✓	✓	✓	
• Delhi	Monitored	✓	✓	✓	✓	✓	✓	✓	✓
• Kochi	Monitored	✓	✓			✓	✓		
• Mumbai	Monitored	✓			✓	✓	✓		
Indonesia	With standard/GV	✓	✓		✓	✓	✓	✓	✓
• Bandung	Monitored		✓		✓	✓	✓	✓	✓
• Jakarta	Monitored	✓	✓		✓	✓	✓	✓	✓
• Surakarta	Monitored								
Japan	With standard/GV	✓		✓		✓	✓	✓	✓
• Chiba	Monitored	✓		✓		✓	✓		✓
• Hamamatsu	Monitored	✓		✓		✓	✓	✓	✓
• Kawasaki	Monitored		✓	✓		✓	✓	✓	✓
• Sagamihara	Monitored		✓	✓		✓	✓	✓	✓
• Sendai	Monitored	✓	✓	✓		✓	✓	✓	✓
• Tokyo	Monitored	✓		✓		✓	✓		✓
• Fukuoka	Monitored			✓		✓	✓	✓	✓
• Hiroshima	Monitored	✓		✓		✓	✓	✓	✓
• Nagoya	Monitored	✓		✓		✓	✓		✓

Countries and Major Cities		Pollutants							
		TSP	PM_{10}	$PM_{2.5}$	Pb	NO_2	SO_2	O_3	CO
• Saitama	Monitored	✓		✓		✓	✓		✓
• Shizuoka	Monitored	✓		✓		✓	✓	✓	✓
Lao PDR	With standard/GV	✓	✓		✓	✓	✓		✓
• Vientiane	Monitored								
Mongolia	With standard/GV	✓	✓	✓	✓	✓	✓	✓	✓
• Ulaanbaatar	Monitored		✓			✓	✓	✓	✓
Nepal	With standard/GV	✓	✓		✓	✓	✓		✓
• Kathmandu	Monitored								
Philippines	With standard/GV	✓	✓	✓	✓	✓	✓	✓	✓
• Manila	Monitored	✓	✓	✓		✓	✓	✓	✓
Republic of Korea	With standard/GV		✓		✓	✓	✓	✓	✓
• Seoul	Monitored	✓	✓	✓		✓	✓	✓	
Singapore	With standard/GV		✓	✓		✓	✓	✓	✓
• Singapore	Monitored		✓	✓	✓	✓	✓	✓	✓
Sri Lanka	With standard/GV		✓	✓		✓	✓	✓	✓
• Colombo	Monitored		✓						
Thailand	With standard/GV	✓	✓	✓		✓	✓	✓	✓
• Rayong	Monitored		✓	✓		✓	✓	✓	✓
• Bangkok	Monitored	✓	✓	✓		✓	✓	✓	✓
Viet Nam	With standard/GV	✓	✓	✓	✓	✓	✓	✓	✓
• Hanoi	Monitored	✓	✓	✓		✓	✓	✓	✓

Note:GV = Guidance Value; TSP = Total suspended particulates; PM10= particulate matter which passes through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter; PM2.5= particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter; Pb = Lead; NO2 = Nitrogen dioxide; SO2 = Sulfur dioxide; O3 = Ozone; CO= Carbon monoxide
Source: Authors, based on responses from surveyof monitoring stations in capital cities.

Figure 3. Type of pollutants monitored in each of the stations (only for capital cities)

Note: THA = Thailand; PRC = People's Republic of China; SRI = Sri Lanka; IND = India; BAN = Bangladesh; VIE = Viet Nam; INO = Indonesia; NEP = Nepal; PHI = Philippines; ROK = Republic of Korea; SIN = Singapore; BHU = Bhutan; JAP = Japan; MON = Mongolia
Source: Authors, based on responses from surveyof monitoring stations in capital cities.



Note: Hong Kong – proposed in 2014; EU = European Union; YRD = Yangtze River Delta; PRD = Pearl River Delta; US EPA = United Nations Environmental Protection Agency; ROK = Republic of Korea; Hong Kong SAR = Hong Kong Special Administrative Region. Hong Kong SAR* = proposed in 2014
Source: Clean Air Asia.

Figure 4. Timeline of establishment of PM2.5 standards in Asia (with reference to US)

In addition to the criteria pollutants listed in Table 10, 15 cities responded that they also monitor volatile organic compounds (VOCs) and heavy metals (As, Ni, Hg). [7]

Monitoring site classification

Based on the results of the survey, most of the stations monitor ambient conditions (Figure 5). With the exception of Seoul, a limited number of cities monitor background conditions. Seoul is also different from the rest of the cities surveyed because its station composition is relatively balanced. It monitors a mix of background, ambient, and traffic conditions. Rapid urban development in Asia also poses a challenge in site classification. Stations previously classified as background had to be re-classified because of urbanization. Some cities also noted the increasing difficulty of selecting monitoring sites due to limited space availability and changing urban landscape.

Among cities included in the survey, only Bangkok and Rayong (in Thailand) and Tianjin (PR China) mentioned having industrial monitoring sites. The lack of industrial monitoring sites may be because most industries are located outside of the cities, or that the industries are within the cities and that opportunities exist for regulatory agencies to expand the monitoring network by requiring the industries to monitor their own emissions (i.e., Rayong). From the same figure, it can be observed that stations monitoring vehicular emissions comprise a substantial share of the total stations. This could be attributed to the increased motorization in Asian cities.

Specific in-situ characteristics

7 Bangkok, Chiba, Delhi, Dhaka, Hamamatsu, Kawasaki, Nagoya, Radshahi, Rayong, Sagamihara, Sendai, Seoul, Shizuoka, Singapore, Tokyo

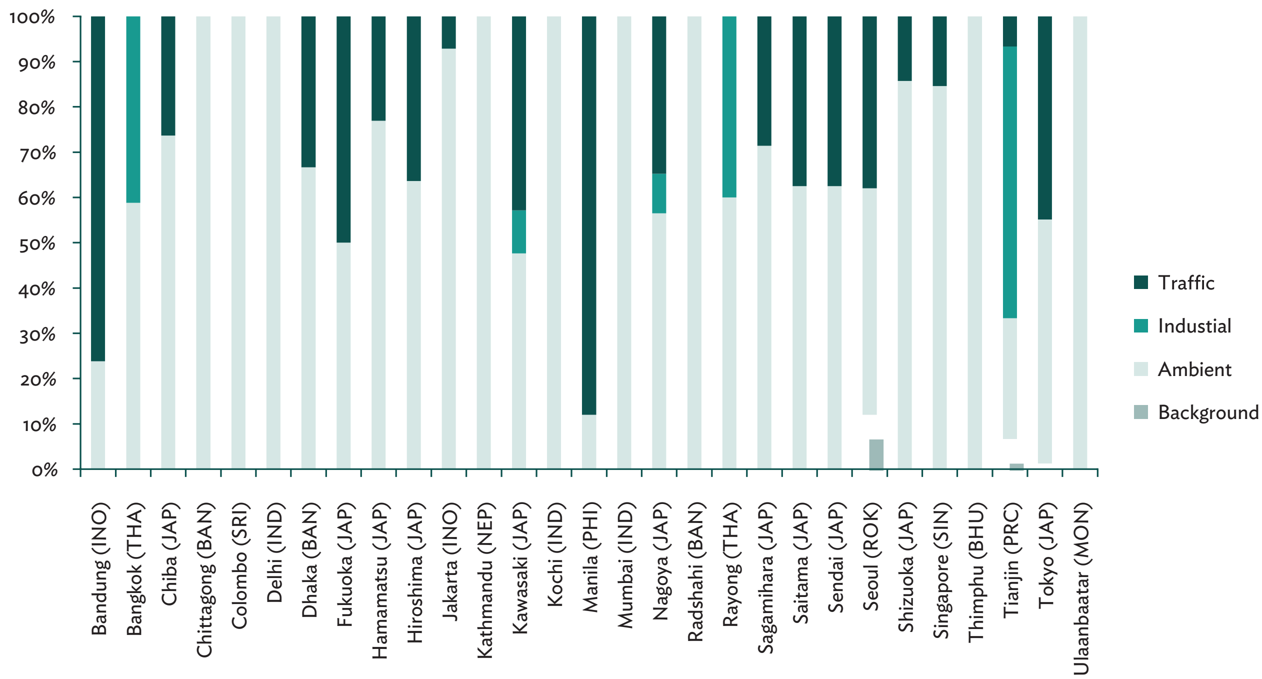


Figure 5. Relative fractions of the type of monitoring sites

Note: Some cities, especially in PR China, are not included in the figure because of incomplete survey response.

Assessment of in-situ characteristics of air quality monitoring stations was included during the detailed assessment of air quality monitoring systems in selected cities (Bangkok, Bandung, Delhi, Hanoi, HCMC, Jakarta, Rayong, Seoul, Surabaya, Singapore, and Ulaanbaatar)[8]. Some of the observed include:

- Most fixed stations were within breathing zone
- There were flow obstructions observed in some of the stations
- Uncertainty regarding representativeness of existing stations

The results of the assessment highlight the a need for periodic review ofsiting in existing monitoring systems across Asia.

A similar observation was found in a recently completed study by the European Environment Agency (EEA, 2013) which helped identify and address the reasons underlying the 'gap' in implementation of air quality policy in 12 European cities. Based on their assessment of 12 cities, local air quality practitioners expressed the challenges in properly classifying monitoring stations based on the EU directives.

Monitoring Meteorological Data

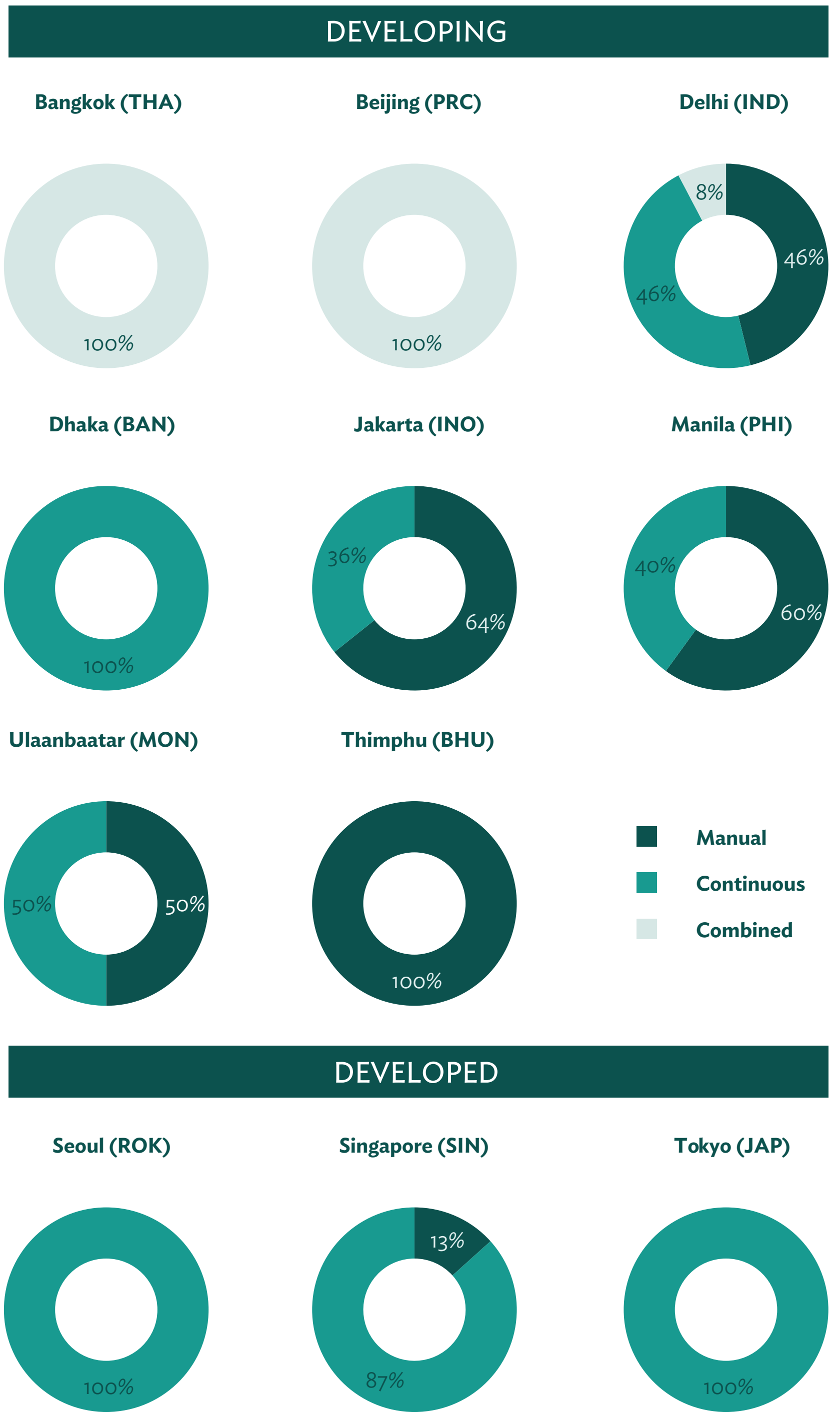
Monitoring results, when supported by meteorological data like wind speed, wind direction, temperature, solar radiation, and relative humidity, can be used to simulate air quality and predict air pollution episodes. The USEPA guidelines require that meteorological data be collected at all NCore stations,[9] as stated in the Code of Federal Regulations (CFR) Chapter 40 Section 58, Appendix D.3.b. However, several monitoring stations in developing Asian cities do not collect meteorological information. The absence of meteorological data reflects the limited modeling and forecasting capacity of most monitoring systems.

Monitoring station type

[8] Additional information about the results of the air quality monitoring systems survey in these cities is available in a separate report.

[9] NCore is a multi pollutant network that integrates several advanced measurement systems for particles, pollutant gases and meteorology.

Based on survey responses, most of the stations are continuous stations (Figure 6). However, if cities from Japan are excluded, monitoring stations in the rest of cities are primarily manual or a mix of both manual and continuous. This could be due to the high capital cost of continuous analyzers. Manual analyzers are often cheaper although sample collection and analysis are more labor intensive.



Note: Some cities, especially in PR China, are not included in the figure because of incomplete survey response.Note: THA = Thailand; PRC = People's Republic of China; SRI = Sri Lanka; IND = India; BAN = Bangladesh; VIE = Viet Nam; INO = Indonesia; NEP = Nepal; PHI = Philippines; ROK = Republic of Korea; SIN = Singapore; BHU = Bhutan; JAP = Japan; MON = Mongolia; Combined = both manual and continuous
Source: Authors, based on responses from surveyof monitoring stations in capital cities.

Figure 6. Percent share on the type of monitoring stations in capital cities

2.2.3 CASE STUDIES: GOOD PRACTICES IN ASIA

Case Study 1: Optimizing number of stations with limited space available in Singapore

The Situation: There is a substantial increase in urban development and industrial activities in Singapore, which could potentially impact air quality. Since the establishment of the first six air monitoring stations (AMS) in 1971, Singapore has been quite successful in continuously upgrading its capacity from continuous monitoring of CO, SO_2, O_3, PM10, and NO_2 in the 1980s to introducing computerized telemetry system in the early 1990s. Despite the improvement in the network, pollution hotspots were not covered in the monitoring network. While there is a strong public demand for location-based real-time AQ information and forecasts, Singapore National Environment Agency is not able to modify the number of stationsbecause of space limitations and limited information on PM2.5 sources from existing monitoring activities.

The Response: To be able to address this, Singapore National Environment Agency implemented the following actions:

- Selected potential locations for additional stations that are state-owned;
- Upgraded the existing monitoring stations to full stations (with more parameters measured) and included more VOC monitoring equipment;
- Acquired mobile vans that include continuous monitors for gases and PM; and
- Developed modeling capability for air quality forecasting, alerts, location-based air quality information and tracking pollution sources.

Case Study 2: Moving from TSP to PM10 and PM2.5 monitoring in Metro Manila

The Situation: A few years ago, most of the monitoring stations in Metro Manila focused on monitoring total suspended particulates (in nine stations), all of which were located along the major roads. The TSP monitors were originally installed for hotspots monitoring from traffic emissions. Recent studies have brought attention to PM10 and PM2.5 because of their adverse impact on human health. In addition, there has been a demand for better understanding of general ambient air quality levels in the city (not only for traffic hotspots).

The Response: With support from various stakeholders, the Environmental Management Bureau (EMB) of the National Capital Region (Metro Manila) and the Air Quality Management Section of the EMB upgraded its monitoring objectives from mostly roadside monitoring to include ambient air quality monitoring. In addition, it expanded the scope of the monitoring, to focus on PM10 and PM2.5, instead of only TSP, to protect public health. It has built on the existing three continuous monitoring stations for PM10 and PM2.5, and plans to add 14 more PM10 and PM2.5 monitors by 2014.

2.3 CHARACTERISTIC 2: PROPER IMPLEMENTATION OF QA&QC PROCEDURES

2.3.1 INTERNATIONAL GOOD PRACTICES

Formulating effective interventions to improve air quality and other related activities such as public advisories and forecasting are hinged on accurate monitoring data. Quality control (QC) and quality assurance (QA) are performed to ensure that the entire process of data collection and management will ultimately lead to valid and reliable data. Quality control refers to the operational techniques and activities undertaken to obtain a specified criteria ofthe measurement, i.e., accuracy and precision. On the other hand, QA is defined as the overall management of the end-to-end process leading to a defined quality of the data product. Quality control includes measurement-related activities such as network operation, calibration, data handling, review, and training, while QA covers all the important pre-measurement phases of monitoring, ranging from definition of data quality objectives and system design and site selection to equipment evaluation, selection and deployment, and operator training (Schwela, 2010). An overview of the key elements of a QA and QC are provided in the table below.

Table 11. Key elements in quality assurance and quality control

Quality Assurance	Quality Control
■ System audits to assure that procedures are being followed or modified to reflect current practice ■ Performance audits to evaluate outputs for external standards ■ Inter-laboratory comparisons and co-located sampling ■ Interference evaluation with reference materials	■ Standard Operating Procedures, revised periodically ■ Periodic instrument calibrations with transfer standards ■ Periodic zeros and spans with performance standards ■ Replicate analyses ■ Cross-instrument comparisons ■ Internal consistency tests

Source: Chow et al, 2012.

The entire QA/QC process can be summarized into three major activities (Table 12). First, is to develop protocols and methods for operating a monitoring network. This includes setting the data quality objectives (i.e., defining what data is acceptable and setting the range of tolerable uncertainties), specifying the measurement methods, and defining the criteria for selecting the equipment and sampling sites. Second, is to determine whether guidelines developed in the first activity are followed. This entails site visits and equipment inspections to ensure that proper operating procedures and calibration guidelines are complied with. The third activity is a precautionary measure of the second step whereby the necessary corrective actions are implemented if, upon examination, the guidelines are not followed. Documentation is an integral part of this activity to track and identify where the errors were committed, and to replicate the processes to arrive at data of known quality.

Personnel training and technical support are also necessary to guarantee that the guidelines listed are being implemented properly. Collaborative reviews with experts from developed countries may also be performed to further improve the process (UNEP & WHO, 1995).

Owing to the difference in the physical and chemical properties of pollutants, the techniques in measuring them vary. A wealth of resources that enumerate such techniques are available at the institutions listed below. An example is the federally-approved methods of chemical analyses for each criteria pollutant by the US EPA (Table 13).

Table 12. The essential components of a QA/QC process

Activities in a QA/QC process	Elements covered
Develop specifications for operating a monitoring network	Data quality objectives Measurement methodology (Reference methods) Equipment selection and operation Site selection (Includes: site classification, distribution, location) Sampling System (Includes: shelter requirements and probe siting)
Assess compliance to the guidelines developed	Station and analyzer operation (Includes: station visits, ensuring that operation procedures are followed, and preventive maintenance) Calibration (Includes: calibration frequency, calibration procedures, zero and span verifications)
Implementing corrective actions to ensure compliance	System audits and station performance (includes independent verifications) Data validation Documentation (Log books and operation manuals) Personnel training and technical support

Source: US EPA, 2013a.

- United States National Institute of Standards and Technology
- Canada's Institute for National Measurement Standards
- European Committee for Standardization
- International Organization for Standardizations

Table 13. Reference methods for criteria pollutants

Criteria Pollutant	Principles of measurement method
SO_2	Spectrophotometry
NO_2	Gas-phase Chemiluminescence
CO	Non-dispersive infrared photometry
O_3	Chemiluminescence
Particulate matter	Gravimetry/ beta-ray attenuation/ light scattering

Note:SO2 = Sulfur dioxide; NO2 = Nitrogen dioxide; CO= Carbon monoxide; O3 = Ozone
Source: Aerosol and Particulate Research Lab-University of Florida, 2013.

More information on the elements in Table 12 can be found at the following:

- Air Planning and Standards, USEPA
  http://www.epa.gov/airquality/montring.html

- National Air Pollution Surveillance Program, Environment Canada
  http://www.ec.gc.ca/rnspa-naps/

- EU Directives for Monitoring Atmospheric Pollution (2004/107/EC & Directive 2008/50/EC):
  http://eur-lex.europa.eu/en/legis/latest/chap15102030.htm

- Foundation Course on Air Quality Management in Asia, SEI
  http://www.sei.se/cleanair/modules.html

2.3.2 STATUS AND CHALLENGES IN ASIA

In determining whether a QA/QC process exists and is implemented in the monitoring systems of Asian cities, the evaluation criteria listed below and their frequency of application were included in the AQ monitoring survey. The words enclosed in parentheses are the shorthand notations used in Figure 7.

- Protocol that ensures the accuracy of measuring devices (Established method)
- Calibration that guarantees that the measured values are true and correct (Calibration)
- Use of certified gases and solutions in calibration (Certified gases)

Figure 7 illustrates that all cities implement a QA/QC process. These cities differ only on how often their QA/QC process is implemented. On one hand, cities in Japan, Singapore, South Korea, and Thailand strictly adhere to measurement methods and regularly calibrate their equipment with standard gases and solutions. The rest of the countries, on the other hand, perform those tasks less regularly. The commonly-cited reasons for this shortcoming are limited resources, manpower, and technical capacity. It might be observed that some cities included in the survey are not represented in the figure. This is either due to incomplete survey responses (e.g. cities in China) or to the absence of monitoring stations (e.g. Vientiane).

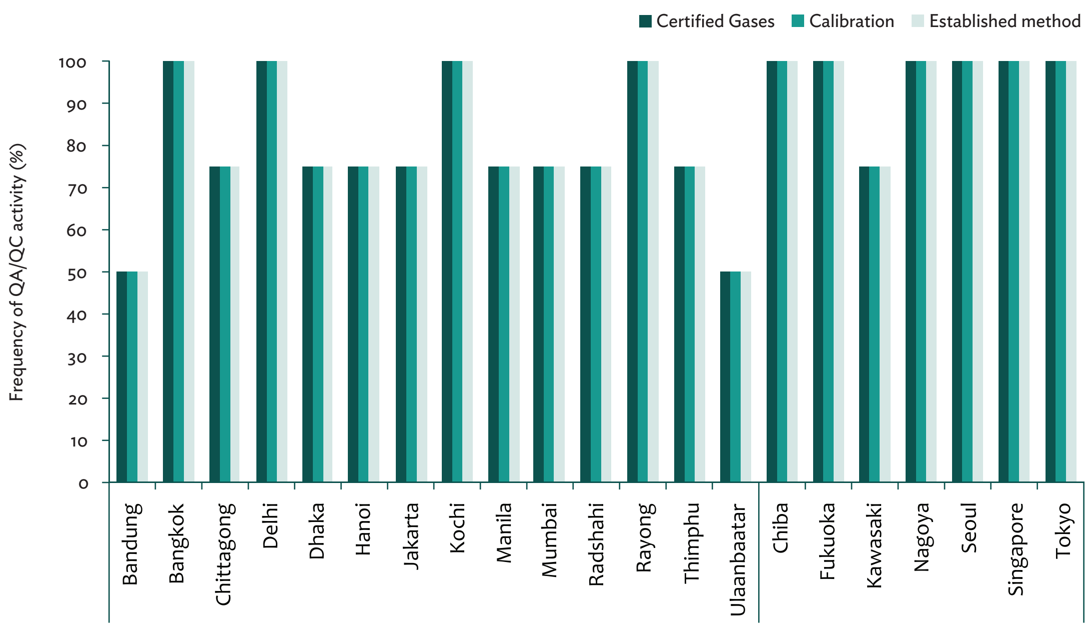


Figure 7. Different indicators of a good QA&QC process and level of implementation in selected cities

Note: THA = Thailand; PRC = People's Republic of China; SRI = Sri Lanka; IND = India; BAN = Bangladesh; VIE = Viet Nam; INO = Indonesia; NEP = Nepal; PHI = Philippines; ROK = Republic of Korea; SIN = Singapore; BHU = Bhutan; JAP = Japan; MON = Mongolia. Source: Authors, based on responses from survey of monitoring stations.

As previously mentioned, different methods can be employed in measuring air pollutants. Table 14 provides an overview of the different measurement methods for PM10 stipulated in their national air management strategies or national guidelines. It is observed that 11 out of 13 countries prescribe gravimetric method for measuring PM10. It is also used in combination with other methods such as beta ray attenuation and tapered element oscillating microbalance (TEOM).

Table 14. Methods of measuring PM10 for different countries

Country	Measurement Method
Bhutan	Gravimetric (based on EN 12341)
PR China	Gravimetric, Beta ray attenuation, TEOM
India	Gravimetric
Japan	Gravimetric, Light Scattering
Lao PDR	Gravimetric, Beta ray attenuation, TEOM
Mongolia	Gravimetric
Pakistan	Beta ray attenuation
Philippines	Gravimetric
Republic of Korea	Beta ray attenuation
Singapore	Gravimetric, Beta ray attenuation
Sri Lanka	Gravimetric, Beta ray attenuation
Thailand	Gravimetric (based on US EPA)
Viet Nam	Gravimetric (based on NILU)

Note: TEOM = Tapered Element Oscillating Microbalance; US EPA = United Nations Environment Protection Agency; NILU = Norwegian Air Research Instituttte.
Source: Collected by Authors from various sources.

Also from Table 14, it can be observed that the measurement methods of countries like Bhutan explicitly state that their methods were derived from existing international standards developed by the EU or the US EPA. Such practice and the similarity of the methods employed can be an indication that guidelines developed and the quality assurance component are technically sound. Recalling Figure 7, it is therefore likely that the inability to follow and implement the plan regularly is the main factor that compromises the quality of the data collected.
More detail on the different measurement methods can be found at the following:

For criteria pollutants

- List of Designated Reference and Equivalent Methods, US EPA, National Exposure Research Laboratory: http://www.epa.gov/ttnamti1/files/ambient/criteria/reference-equivalent-methods-list.pdf

Particulate matter

- Guide to the Demonstration of Equivalence of Ambient Air Quality Monitoring Methods: European Council Working Group on Guidance for the Demonstration Of Equivalence: http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf
- Measurement of PM10 Particles, Norwegian Institute for Air Research: http://www.nilu.no/projects/ccc/manual/documents/03_15-Measurement%20of%20pm10%20particles.htm

Based on the results of a detailed assessment of air quality monitoring systems in 11 Asian cities, technical understanding of the QA & QC protocols generally exists, however, implementation is hindered by limited human and financial resources. A possible way forward to reduce the cost of QA & QC is to adopt monitoring equipment with lesser complexity (i.e., passive monitors), as long as it is inline with the defined air quality monitoring objectives. Phased expansion (in terms of scope and complexity) of air quality monitoring systems should be considered, especially from cities with limited resources.

There are some existing efforts to overcome QA&QC constraints in Asia, as provided in the succeeding section.

2.3.3 CASE STUDIES: PRACTICES IN ASIA

Case Study 1: Sustaining air quality monitoring network in Delhi through subcontacting

The Situation: Sub-contracting the operation of the air monitoring stations to equipment suppliers can help sustain an air quality monitoring network especially with an organization, such as Delhi Pollution Control Committee (DPCC), with minimal staff working on air quality. The DPCC oversaw the operation of six air quality monitoring stations at i) Civil Lines, ii) Punjabi Bagh, iii) Mandir Marg, iv) Anand Vihar, v) IGI airport and vi) R K Puram. The stations were managed and operated by an appointed contractor/ operator which was also the equipment supplier. The equipment supplier/operator was selected through an open tender.

The Response: The DPCC has adopted a contracting system to purchase and operate air quality monitoring stations. Subsequently, each station may have different sets of equipment. The merit of this arrangement is that various technologies can be applied and DPCC can gauge the performance of each one. However, it is possible that there are variations of measured AQ concentrations among different types of monitors even in the same environment as these instruments may be affected by temperature, humidity, pressure, and other micro-environmental factors (as seen in Table 15). Comparisons among different PM2.5 monitoring instruments was done in Hong Kong. It is observd that apart from Kimoto, all other instruments were within reasonable range of the relative reference value which indicates accuracy.

It is therefore of vital importance that these instruments have to conform to the same standards, as the sensitivity and accuracy tolerance vary with different equipment standards. Moreover, regular calibration of these instruments by an independent body (perhaps the DPCC) is necessary to ensure normal operations.

Table 15. Comparison of different PM2.5 samplers

Instrument	BGI	High	Mini Volume	URG	Y-Shape	Kimoto	Relative Reference
Mass Concentration(ave) Gap	56.0	54.4	56.7	56.4	59.0	51.5	56.5
Difference to Relative Reference	-0.5 to	-2.1 to	0.2 to	-0.1 to	2.5 to	-5 to	
% range	-0.9	-3.7	0.4	-0.2	4.4	-8.8	

Note: Relative Reference represents the Relative Reference Value, which is the average mass concentrations obtained by different filter-based samplers. Mass concentration is expressed in μg/m3 = micrograms per cubic meter.
Source: Hung, 2012.

Case Study 2: Creating local support systems to ensure data quality in Viet Nam

The Situation: Sufficient resources and technical capacity are needed to properly maintain an air quality monitoring system. This may be challenging for some developing cities because of limited resources available. This has been the case in Hanoi where the state of air quality monitoring stations operated by the Center for Natural Resources and Environmental Monitoring and Analysis (CENMA) of the Hanoi Department of Natural Resources and Environment (DONRE) under the Hanoi's People Committee has been slowly deteriorating. In 2007, reports mention that of the seven air monitoring stations; only one station provides partly reliable data (SVCAP, 2007). The remaining stations were either not operating any more or are not operating properly to be able to deliver reliable data (SVCAP, 2007).

The Response: To support cities in developing and improving their air quality monitoring systems, the Center for Environmental Monitoring (CEM), a subsidiary body under the Viet Nam Environment Administration, was set-up in 2008 to organize and implement the national environmental monitoring, to act as coordinator for the national environmental monitoring network, to manage and improveenvironmental monitoring data and to prepare state of the environment reports.

The CEM has already helped install monitoring stations in a number of provinces in Viet Nam, including Da Nang and Nha Trang. It has also developed a mobile calibration system in 2012 and has established QA & QC guidelines for its manual stations. The CEM can provide a monitoring station to the cities/provinces provided that they can support the maintenance and operation of the station. Through this network, CEM is able to provide QA and QC services to the different cities and provinces to ensure reliability of data. The CEM also provides training support and acts as a national coordinator for provincial environmental monitoring centers in the country.

As seen in the case of Viet Nam, one way to address resource constraint is to have a specialised organization to support cities with limited technical resources in QA & QC.

Case Study 3: Making adjustments in the operation of the monitoring stations to adapt to local conditions in Ulaanbaatar

The Situation: Air quality monitoring in Mongolia started as early as 1976 using wet chemical method measuring SO_2 and NO_2 in a number of sites in Ulaanbaatar. In 2010, there was a loan from the French government for procurement of six automatic monitoring stations measuring PM_{10}, SO_2, NO_x/NO_2,O_3,CO, staff training, and a five-year support for consumables and spare parts. The loan from the French government included training of staff for three weeks in Mongolia and two weeks in France. The stations were managed and operated by the Central Laboratory of Environment and Metrology (CLEM) under the National Agency for Meteorology and Environment Monitoring (NAMEM). They experienced challenges in operating of the equipment because of the high pollution concentration in the city.

The Response: The QA and QC process is crucial in ensuring good and adequate data are collected so that the possibility of misinterpretation of air quality data can be minimized. The CLEM staff made adjustments in the operation of the monitoring stations to adapt to local conditions. For example, while the equipment manual states that the PM filters need to be replaced monthly, the CLEM staff change the PM filters every two weeks instead because of the dusty conditions in Ulaanbaatar. This change in procedure needs to be considered in evaluating PM concentration levels.

2.4 CHARACTERISTIC 3: SUSTAINABLE OPERATION OF THE AIR QUALITY MONITORING NETWORK

2.4.1 INTERNATIONAL GOOD PRACTICES

Continuous support is imperative in sustaining the operation of monitoring systems. Although a significant proportion of the budget goes to the acquisition of monitoring equipment, care must be taken to ensure that support is extended to other monitoring functions such as equipment operation and maintenance, data transmission, and data analysis. For the reason that the success of the latter functions depend on technical capacity, support, therefore, must not just be monetary but it must also include personnel development.

For personnel development, the staff needs to undergo periodic training to continuously update their knowledge. This also serves as a guarantee of their technical competence. National governments, organizations, and research institutes offer training programs for monitoring personnel. The USEPA, for example, has an Air Pollution Training Institute (APTI) and Air Pollution Distance Learning Network (APDLN) dedicated for such purpose.[10] It is likewise important that the number of people assigned to execute different monitoring functions is adequate if they are to perform their tasks properly. An overburdened staff may produce unreliable outputs or may altogether neglect some assigned tasks.

Focusing on the financial aspect: In addition to the capital cost of purchasing the equipment, budget must be allocated for equipment maintenance and purchase of consumables like filters and calibration gases. Moreover, because the equipment, regardless of how well they are maintained, is only functional for a defined period, budget must likewise be set aside to support a replacement plan which is typically every 8 to 10 years. This is important in ensuring that the data collected from the monitoring equipment are accurate and reliable. Table 16 provides an overview of design and operation of an air quality monitoring system and budget estimates.

Design of an air quality monitoring system	Setting up of air quality monitoring network	Operation and maintenance of the monitoring network
■ Setting air quality monitoring objectives and data quality objectives ■ Number of stations and site selection ■ Technical design of AQ monitoring network ■ Allotment of human and financial resources	■ Setting up a standard station - Shelter with electricity - Analyzers, calibration system - Cabinet for storage - Consumables: tubing, standard gas, air conditioning system ■ Estimated budget: **USD 200,000 to 300,000** per station for automatic monitoring station	■ Quality assurance and quality control ■ System and performance audit (internal and external) ■ Parts and Equipment Replacement ■ Target lifetime of equipment: **8-10 years** ■ Estimated maintenance cost ranges **USD 20,000 to 25,000** per station per year ■ Routine personnel training

Table 16. Overview of air quality monitoring system design and operation with budget estimates

Source: Authors.

Currently, various funding mechanisms are used by cities to establish and operate air quality monitoring systems. A summary of typical and innovative financial mechasims to sustain operation of AQ monitoring systems is provided below. A combination of these mechanisms may be explored to sustain air quality monitoring systems in Asian cities.

[10] More information is available through this URL: http://www.epa.gov/apti/broadcast.html

Government-appropriated Budget. In the Asian cities covered by the survey, the level of support for air quality monitoring is intricately linked to their level of economic development. Seoul, Hong Kong SAR, Singapore and cities in Japan, for example, have extensive and well-developed monitoring systems supported by government funds. They also have modeling and forecasting capabilities which are largely non-existent in their less-affluent counterparts, as well as replacement plans for monitoring equipment, whereas most other cities are plagued with equipment malfunction and unavailable replacement parts due to insufficient budgetary support.

Grants and Loans from the International Lending Institutions and Foundations. Most air quality monitoring networks in Asia started with bilateral assistance or loans from lending institutions and foundations whereby a significant fraction of the funds is used to cover the purchase and installation of the monitoring equipment. These assistance, however, are not extended indefinitely. Though grants and loans can help kickstart AQ monitoring systems, government support is necessary for its sustainability. One example where the AQ monitoring was initially supported through international grants and then sustained through strong government supportis Thailand (See Section 2.4.3).

Tax-Generated Funding. The practice of generating financial resources from the fuel tax in Delhi is worth highlighting as an example of an innovative funding mechanism. The deterioration of air quality in the city over the past decades has prompted its local government to seek alternative sources of funding for its AQ monitoring stations by imposing a fuel tax, in which 0.25 indian rupees per liter of diesel was collected and transmitted into an Air Ambience Fund. The levy is collected by the Department of Trade and Taxes and used for the reimbursement and the operations and maintenance of AQ monitoring stations. Similar examples are observed in Sri Lanka and Philippines.

Proprietary Innovative Technologies. The "Air de Paris" balloon in Paris, a partnership between Airparif® and Aerophile, is an effective and innovative way in engaging the general public on air quality awareness in their cities through a tourist attraction-cum-scientific tool (Bitterman, 2010). Its highly creative and eye-catching design combined with its built-in utility lends the possibility of deploying similar mechanisms that could be packaged with paid promotion so that operating expenses will be shouldered by interested advertisers. Funds generated from the balloon may help support operation of AQ monitoring stations. In case of Paris, the installation of the complete system is estimated to cost about 920,000 Euro (about 1.25 million USD). Based on "Air de Paris" experience, it is estimated that income generated from balloon ticket sales, sponsorship/advertisements, and events reached 1.09 million Euro (about 1.4 million USD) in one year. Recovery of the initial investment is possible after a couple of years.

Private Sector Support. When appropriately engaged, other stakeholders can play an active role. In Metro Manila, a public-private partnership called Metro Weather[11] has successfully established a network of 30 automated weather stations capable of providing free and near real-time weather data that can be used to prepare for severe weather conditions such as tropical cyclones and heavy flooding. Collaborating on this effort were the academe, the local authorities, non-profit organizations, and even petrol and mobile companies, with their expertise and assets synergized to achieve accurate and valuable results. Such collaboration could be extended or new ones established to generate funds to operate air quality monitoring stations.

Establishing Regional Resource Centers. In Cebu City, Philippines, a team of pulmonary experts in the early 1990s pooled their resources to establish BAGA (Breathe Always Good Air) (BAGA means lungs in local language), which aimed to acquire various medical equipment to service hospitals lacking much-needed facility. Now 23 years in operation, BAGA is currently engaged in the business of leasing pulmonary equipment (such as ventilators and x-ray machines) and services to hospitals, now having a 24-hour hotline and medical assistance staff to ensure proper handling of the machines, even expanding to non-hospital based pulmonary centers, scholarship programs, and libraries. With its evident success, the BAGA model can possibly be extended and applied to the establishment of a centralized source of AQ monitoring equipment and personnel in the region. The monitoring equipment may be rotated/lent to different cities to monitor air quality during critical periods.

---

[11] More information on Metro Weather available at http://panahon.observatory.ph/faq.html

2.4.2 STATUS AND CHALLENGES IN ASIA

Human and financial resources are the foundation of a sustainable monitoring network. It may be expected that cities with inadequate resources are less successful in sustaining their monitoring operations or have limited monitoring.

As an illustration, limited financial and human resources in Ulaanbaatar for maintenance and operation of their AQ monitoring network makes periodic implementation of quality assurance and quality control a challenge. Hanoi, also suffers from the same predicament: only 1 out of its 7 monitoring stations remain functional because the rest of their decade-old equipment are already malfunctioning and there is little or no budget allotted for purchasing new ones or replacing the broken parts. Moreover, because the equipment is dated, the acquisition of spare parts becomes a challenge as they may have been already phased out. This is the same case in Kathmandu wherein the operation of monitoring stations ceased in mid-2008 because of limited resources.

Table 17 provides a compilation of costs incurred for AQ monitoring systems in selected Asian cities. This is based on information provided by cities from personal communication. It can be noted that the estimated capital cost for one fixed monitoring station in a city can vary and even cost twice as much in another city. This was observed in the case of Hanoi, where a single station can cost up to 300,000 USD as compared to Bangkok (costing around 146,200 USD). Of course, this depends on the number of analyzers in the station and available suppliers in the country. The operating cost in different cities also differ but are generally within the range of 20,000 to 25,000 USD per fixed station per year.

Table 17. Overview of budget estimates for AQ monitoring systems in selected Asian cities[1]

City	Population (million)	Capital Cost (per station, USD)	Operational Cost (in USD)	Total Cost (in USD)
Baguio (PHI)	0.3	—	17,000-20,000 (1 sampler going around 25 sampling sites)	—
Bangkok (THA)	5.7	146,200 (for each fixed station)	4,200-27,200 (per station); 128,300 (consumables, parts, and supplies for total network); 126,400 (equipment repair for total network)	—
Delhi (IND)	16.6	190,000 (for each fixed station)	-	—
Hanoi (VIE)	6.6	300,000 (for each fixed station)	23,000-25,000 (per station)	—
Jakarta (INO)	9.7	—	530,000 (operation and maintenance of 5 continuous stations); 30,000 (operation and maintenance of 9 manual stations)	—
Rayong (THA)	0.6	146,200	4,200-27,200 (per station); 128,300 (consumables, parts, and supplies for total network); 126,400 (equipment repair for total network)	—
Singapore (SIN)	5.2	—	540,000-620,000 (for total network comprising 14 stations including consumables, utilities and telecommunications)	460,000 (capital and operating cost per station)
Ulaanbaatar (MON)	1.2	—	43,000 (operations including staff time for 6 manual stations); 660 (maintenance for total network)	2,167,200 (French Government Loan- for procurement of 6 fixed stations, staff training, and 5-year support for consumables and spare parts)

Note: [1]data unavailable for some cities.
Note: PHI = Philippines; THA = Thailand; IND = India; VIE = Viet Nam; INO = Indonesia; ROK = Republic of Korea; SIN = Singapore; MON = Mongolia.
Source: Authors, based on personal communication with cities. It is noted that the table entry/format depends on the information which could be provided by local contacts.

The number of personnel involved in monitoring operations as well as their technical capacity is strongly related to financial support. Singapore sends their personnel to other countries for training. Singapore also has staff dedicated for disseminating information and auditing monitoring stations whose operations were outsourced to an independent contractor. This is in contrast to Ho Chi Minh City whose personnel responsible for air quality monitoring are also tasked to monitor other environmental concerns.

Monitoring stations in Delhi and Ulaanbaatar are also undermanned which necessitates them to perform several monitoring functions (i.e. maintenance and operation of equipment, performing QA/QC, and information dissemination) simultaneously. Most of them also lack the necessary capacity to operate and maintain the monitoring equipment. This is problematic because 67% of the cities rely on full-time staff to carry out the activities (Figure 8).

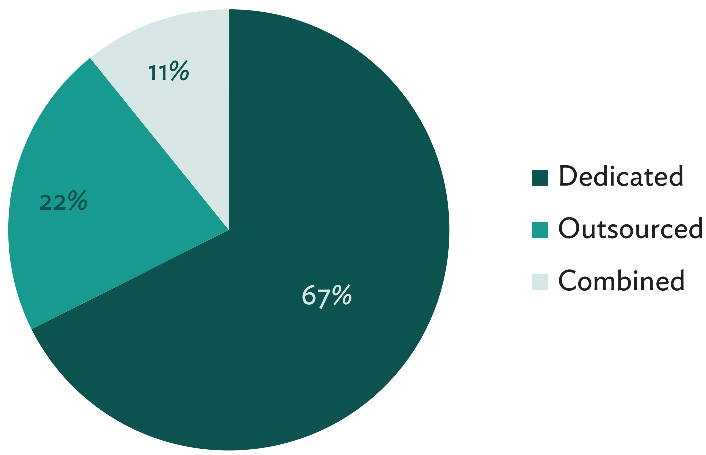


Figure 8. Classification of how air quality monitoring is implemented in Asian cities in terms of manpower

Cities like Bangkok , Delhi, and Singapore find it more workable to outsource the operation of the some of the monitoring equipment because the contracted company already provides both the technical support and the equipment maintenance. It is also advantageous because it frees up their staff to focus on accomplishing other monitoring functions such as data processing and information dissemination. This is an option for Asian cities to consider especially if there is limited technical staff to operate the AQ monitoring stations in the city. Nonetheless, it is important to set-up additional auditing processes either internally or externally to ensure proper implementation by the contractors.

Creating a platform for city AQ monitoring personnel to share with their experiences and practices with one another is a potential opportunity to help improve their capacity. This may be explored by South-South twinning activities. The twinning activities promote inter-city and region-wide sharing of information and experiences towards generating insights that will encourage replication of the best practices of mentor cities. In developing potential city twinning arrangements for air quality monitoring, it is recommended that these are taken into consideration:

- Similarity in terms of general city characteristics
- Current status of the air quality monitoring systems and objective for monitoring
- Performance of mentor cities on five essential characteristics of a good air quality monitoring system

2.4.3 CASE STUDIES: GOOD PRACTICES IN ASIA

Case Study 1: Sustaining air quality monitoring network in Thailand through proper planning

The Situation: As previously mentioned, most AQ monitoring networks in Asia started with bilateral assistance or loans from lending institutions but this assistance, however, is not extended indefinitely. Given this, combining the monitoring plan with the budget plan is integral in sustaining the operation of the monitoring network. The experiences in Ho Chi Minh City, Hanoi, and Manila whereby the monitoring operations are often hampered by equipment failures highlight the importance of such coupling. Thailand is not unlike most Asian countries in terms of how its monitoring network was established. It received assistance from the governments of Japan and Sweden in the early stages of its efforts to monitor air quality. Shown below is the chronology of Thailand's monitoring network from the establishment of its National Ambient Air Quality Standards in 1981 to its current operations that consist of 63 ambient stations and six mobile units.

1981	National Ambient Air Quality Standards were promulgated (subsequently revised in 1995, 2001, 2004, 2007, 2010,--)
1983	The first air quality monitoring system : 8 stations located in BKK (not on-line system)
1987	The first on-line and real-time continuous air quality monitoring system consisted of 5 stations located in Samut Prakan (JICA's assistance)
1991	On-line and real-time continuous system : 4 stations located on the curb-sides in BKK
1992	PCD with the technical assistance from the Swedish Government started preparing the design of a nation-wide ambient air quality monitoring network and a meteorological monitoring network
1996	The nation-wide ambient air quality monitoring network was gradually developed by put in several phases

Figure 9. The evolution of Thailand's monitoring network

The Response: Thailand was able to sustain and expand its monitoring network because of thorough planning from end-to-end, considering their monitoring objectives, operational requirements, timelines, and budget allotment. Continuous review exercises to improve the air quality monitoring system have also been very effectively done. Thailand's Pollution Control Department (PCD) determines which management option to undertake depending on the annual budget allocated for air quality monitoring, which allows flexibility to the air quality monitoring works done by the government or private sectors.

Table 18. Different management options for Thailand's monitoring network according to the budget available

Budget allocation	Management Option
If there is sufficient budget for all stations	All stations will be under a service contract
If there is sufficient budget for most of the stations	Most stations will be under a service contract while some are operated by PCD
If the budget is insufficient	Most stations will be operated by PCD while some may be considered for shut down or PCD may discontinue measurement of some pollutants

Note: PCD = Pollution Control Department.
Source: Suwanathada, 2012.

Case Study 2: Exploring innovative mechanisms to finance AQ monitoring in Sri Lanka

The Situation: The establishment and operation of monitoring networks can be costly. For this reason, finding innovative mechanisms to sustainably finance monitoring networks is often a challenge for most developing countries whose resources are limited. Sri Lanka is no different; 15 years after the lawsuit calling for better air quality was filed, it has yet to establish a comprehensive air quality monitoring system.

The Response: In 2003, the Vehicle Emission Standards, Fuel Standards, and Emission Standards for Importation of vehicles have been implemented in an effort to limit air pollution particularly from mobile sources. To support that law, the Vehicle Emission Testing (VET) program was carried out in 2008 which mandated the testing of carbon monoxide and hydrocarbon emissions for petrol vehicles and smoke opacity for diesel vehicles. A vehicle emission certificate, which is necessary to obtain a vehicle license, is only issued if the emissions comply with the standards. Testing centers accredited by the Central Environment Agency (CEA) collect fees (shown below) to check and issue vehicle emission certificates.

A tenth of their revenue is remitted to the CEA to be used for its air quality management operation called **Project Blue Sky 2020.** Currently, using the revenue from the VET program, the CEA is in the process of purchasing four fixed and one mobile air quality monitoring stations in Colombo. Upon availability of funds, the CEA plans to purchase more monitoring equipment to cover more cities.

Table 19. Testing fees for types of vehicles and fuels used

Cost of Testing[1]		Vehicle Type and Fuel Used
Rs	USD	
355	2.67	Motor bicycle (petrol, diesel)
435	3.28	Three wheeler (petrol, diesel)
950	7.15	Motor car (petrol, diesel)
1,030	7.76	Dual purpose vehicles (petrol, diesel)
1,350	10.17	Motor lorry (petrol, diesel)
870	6.55	Motor coach (petrol, diesel)
870	6.55	Bus (petrol, diesel)
1,430	10.77	Prime mover (diesel)

[1]Exchange rate as of 27 August 2013.
Note: Rs = Sri Lankan Rupee.
Source: Department of Motor Traffic, 2011.

Case Study 3: Optimizing resources through outsourcing AQ monitoring in Malaysia

The Situation: Operating an air quality monitoring network requires several personnel to handle different components of the monitoring system that range from equipment operation and maintenance to data management. In most countries in Asia, this is a concern because the Ministry of Natural Resources and Environment that is tasked to monitor air quality is often undermanned understaffed. This usually leads to overburdened personnel assigned to simultaneously perform several air quality monitoring tasks. In some cases, those same personnel are even assigned to monitor other environmental parameters such as those for water quality. Malaysia has 52 continuous air quality monitoring stations and 14 supplementary manual air quality monitoring stations. Like most countries, Malaysia also faced the challenge of operating its monitoring networks given the limited manpower.

The Response: In 1995, Malaysia outsourced the data collection aspect of monitoring (including equipment maintenance) to an independent contractor to allow its staff to focus on data management and communication. Outsourcing an aspect of air quality monitoring operation is one way of augmenting manpower limitation. However, in addition to being mindful of the monitoring objectives, several factors such as identifying which aspect of the operation is outsourced, data ownership, and data quality must be considered. The advantages and disadvantages of outsourcing must likewise be accounted for. On one hand, some of the advantages include easier management of the network as some of the tasks are assigned to the contractor, better focus on data management, and faster response to equipment repair. Disadvantages, on the other hand, include costs, decline in the environment ministry's expertise on equipment operation and maintenance, and concerns on data security and potential conflicts on data ownership, which may lead to difficulty in accessing data by research institutions.

The potential conflict on data ownership was avoided by an agreement to have the Department of Environment purchase the data from the contractor. To ensure the reliability of data collected, the contractor is required to submit regular reports on quality assurance and quality control checks performed. The Department of Environment also conducts independent audits to verify the veracity of the reports submitted as well as the reliability of the data purchased.

2.5 CHARACTERISTIC 4: EFFECTIVE COMMUNICATION OF AIR QUALITY INFORMATION TO STAKEHOLDERS

2.5.1 INTERNATIONAL GOOD PRACTICES

The primary objective for establishing an air quality monitoring system is to protect public health. Achieving this objective is also dependent on how well air quality information is communicated to the public for them to effectively respond to, and protect themselves from impacts of air pollution. In the long term, public awareness on air quality is also instrumental because it elevates the issue to the policy agenda which, in turn, is hoped to lead to better support for air quality management.

Communication of air quality information can be said to be effective if it reaches the general public in a timely manner. Listed below are the common information dissemination platforms used.

- Published (printed) reports – reports, brochures, papers
- Print media – newspapers
- Broadcast media – television and radio
- Website – online databases
- Email or mobile alerts
- Public display screens or booths / information boards
- Internal communications/ requests

In recent years, the use of social networking and micro-blogging sites is becoming widespread in an effort to make access to information easier and reach wider audiences. In terms of ensuring timely reporting, some regulatory commissions like the European Union specify the reporting frequency of the different pollutants in Articles 26 and 27 as well as in Annex XVI of the Directive 2008/50/EC. The average concentration of Benzene, for example, must be reported at least once every three months, while the ambient concentrations of PM10 must be updated daily or hourly, if possible. The US EPA also has a similar mechanism but it also provides forecasts in addition to real-time reporting of air quality information.

To effectively communicate air quality information to the public, it is important that the information is communicated in a simple, concise and understandable manner. They may not have the necessary background to understand and appreciate raw information on air pollutant concentrations, dose-response, and emissions inventories. The use of air quality indexes is prevalent in communicating air quality information to the public by national and city governments because it transforms the different components of air pollution (i.e. levels of different pollutants and their threshold values) into a single value which is then grouped under simple gradations ranging from safe to unsafe levels. Public health warnings and action to be undertaken by their constituents are provided together with the corresponding index category.

The AQI converts pollutant concentrations to a number on a scale. The scale is further divided into bands which reflect the severity of the pollution. Each AQI band corresponds to a defined pollution concentration. The pollution concentration between the bands is linearly interpolated. Any numerical value of an API falling into a certain API interval, say 51-100, gives the same information and the same color identification.

Depending on the AQI value, these bands could be defined as "good", "moderate", "unhealthy for sensitive groups", "unhealthy", "very unhealthy", and "hazardous" which have different meanings for different segments of the population. The index is also color-coded to make the information more comprehensible and visually appealing (see Table 20).

Table 20. Air Quality Index of US EPA including different bands and their corresponding meaning

Numerical Value	Levels of Health Concern	Meaning
0 to 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk
51 to 100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution
101 to 150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected
151 to 200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious effects
201 to 300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected
301 to 500	Hazardous	Health alert: everyone may experience more serious health effects

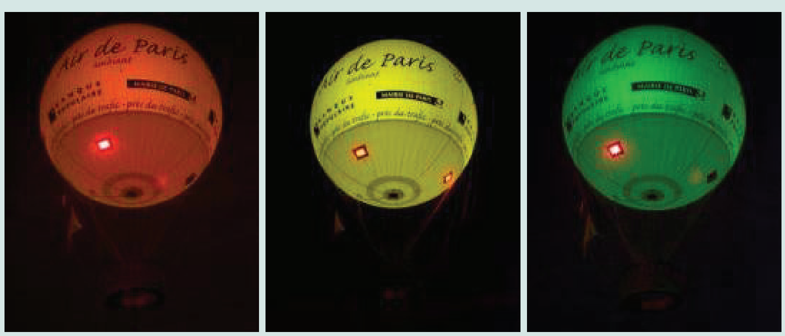
Source: US EPA Air Quality Index (AQI) – A Guide to Air Quality and Your Health, 2013b.

Generally, however, the indexes developed vary from one country to another in terms of the type of pollutants monitored, the range of values, as well as the banding.

Indexes are not the only form of expressing air quality information. In most cases, indexes are enhanced with other data visualization tools such as the geographical information system (GIS) to show the spatial variation of air quality and distribution of air pollutants. Some cities also take advantage of novel technologies to innovatively convey air quality information. Paris, for example, communicates its air quality index for urban and traffic conditions in colored air balloons (Box 1). Another example is the art installation in Seoul's Peace Park whose 27 segments representing different monitoring areas emit different light intensities according to pollution levels (Box 2).

Box 1. Paris, France: "Air de Paris" balloon

Developed in partnership with AIRPARIF®, the balloon's color represents two air quality indexes (1- for urban sites; 2-for traffic stations) in Paris every hour.



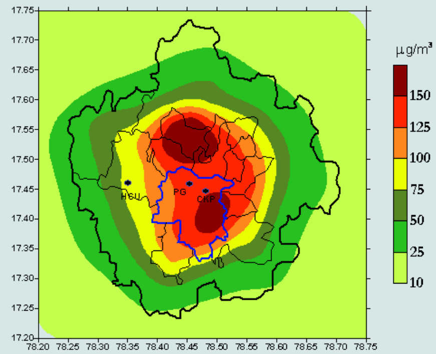
Very good | Good | Medium | Bad | Very bad

The indexes illustrate the levels of nitrogen dioxide, ozone and particulates, air pollutants which are most problematic in large European cities. The color of the balloons is based on the color palette of the Index CITEAIR.

Source: http://www.ballondeparis.com/fr/ballondeparis/i12-la-couleur.

Box 2. Seoul, South Korea: Living light sculptures of air quality

In Seoul's Peace Park lies an art installation which provides the public real-time information on air quality in the city. It was created by Soo-in Yang and David Benjamin of The Living and was commissioned by the Ministry of Environment.



The structure is made of 27 transparent, luminescent segments each representing different areas in the city where there are monitoring stations. Every 15 minutes, the map goes dark and then the segments light up in order of the neighborhood with the best air quality through to the worst air quality at that time. It can also show the year-on-year improvement (only segments with improvement remain lit).

Source: http://www.wired.co.uk/news/archive/2011-01/25/seoul-living-light-air-quality.

2.5.2 STATUS AND CHALLENGES IN ASIA

There is a significant disparity in communicating air quality information to the public in Asian cities and countries.

Ways of presenting air quality information

Table 21 provides an overview of the different ways of presenting air quality information in Asian cities based on survey results. The abbreviations in the table as well as the succeeding figure stand for the following:

- "raw number" – raw data is shared in numerical form
- "raw graph" – raw data is shared in graphical form
- "conc" – air quality data is expressed as concentration
- "stats" – air quality data has undergone statistical analyses (e.g. expressed as percentiles)
- "spatial" – air quality data is represented spatially
- "text" – data has an accompanying text describes the air quality

From the table, it can be observed that based on survey results, only Bangkok, Rayong, and Seoul use the whole spectrum of tools for data communication, while the rest of the cities use a limited combination of the tools available.

Table 21. Different methods of communicating air quality information in Asian Cities

Cities	Raw Number	Raw Graph	Conc	Index	Stats	Spatial	Text
Bangladesh							
Dhaka		•	•	•			•
Chittagong		•	•	•			•
Radshahi		•	•	•			•
Bhutan							
Thimphu	•	•	•	•			•
Japan							
Chiba	•	•	•		•	•	
Fukuoka	•	•	•				•
Hamamatsu	•	•	•		•	•	
Hiroshima	•	•	•		•		•
Kawasaki	•	•	•		•		•
Nagoya	•	•	•		•		•
Sagamihara			•		•	•	•
Saitama	•	•	•	•	•		
Sendai			•				•
Shizuoka	•	•	•		•		•
Tokyo			•	•	•		•
India							
Delhi	•	•	•		•		•
Kochi	•		•				
Mumbai	•	•	•				•
Indonesia							
Jakarta	•	•	•	•	•		•
Nepal							
Kathmandu*							
Mongolia							
Ulaanbaatar			•	•			
Philippines							
Manila	•	•	•	•	•		•
PR China							
Beijing	•		•	•	•	•	•
Hangzhou				•	•		•

Cities	Raw Number	Raw Graph	Conc	Index	Stats	Spatial	Text
Xian	•	•	•	•	•		•
Republic of Korea							
Seoul	•	•	•	•	•	•	•
Singapore							
Singapore			•	•	•		•
Sri Lanka							
Colombo		•					
Thailand							
Bangkok	•	•	•	•	•	•	•
Rayong	•	•	•	•	•	•	•

*Stations were not operating.
Note: Some citiesare not included in the figure because of incomplete survey response. THA = Thailand; PRC = People's Republic of China; JAP = Japan; BAN = Bangladesh; SRI = Sri Lanka; IND = India; INO = Indonesia; NEP = Nepal; ROK = Republic of Korea; SIN = Singapore; BHU = Bhutan; MON = Mongolia.
Source: Authors, based on responses from surveyt of monitoring stations.

Conveying air quality information as pollutant concentrations is the most common ways of presenting air quality information, whereas presenting data spatially is least practiced. Moreover, in general, only a lesser fraction of cities employ communication tools that require more intensive data processing such as developing an index, running statistical analyses, and spatially representing air quality information. Based on the assumption that simple and visual information is more readily understood compared to unprocessed data, the observations of air quality monitoring survey results reveal that air quality communication in Asian cities may not be as effective because the public may not easily understand the information that they are receiving. Pollutant concentrations, for example, will be incomprehensible to the public if the implications of such concentrations are not explained well.

In addition to influencing how data is understood, the preference for a set of communication tools can also be indicative of the monitoring capacities of the cities surveyed. In cities that present primarily raw monitoring data, it is possible that they may not have the necessary manpower or the technical capacity to process and simplify the data. The lack of spatial data visualization can likewise be indicative of the lack of integration and coordination of the different monitoring systems within the cities, or cooperation across different cities.

Use of air quality index

As previously discussed, use of air quality (and similar) index is one way to present information to the general public in a simple manner. However, only 55% of the cities included in the air quality monitoring survey mentioned that they use indexes. Use of AQI can be further utilized by Asian countries and cities.

Table 22 presents an overview of the establishment and application of air quality indexes in Asia. Only seven of the 19 countries/cities included in Table 21 fully implement AQIs. This includes Brunei Darussalam, Japan, Malaysia, Republic of Korea, PR China, Singapore, and Thailand. There were a number of countries which had national guidelines for indexes, but these are only implemented in few cities or not implemented at all.

Table 22. Overview of air quality (and similar) indexes in Asia

Countries	Status	Official Name	Reporting Frequency	Pollutants Included
Afghanistan	—	—	—	—
Bangladesh	Proposed	Air Quality Index	Daily	Not indicated
Bhutan	—	—	—	—
Brunei Darussalam	Implemented	Pollution Standard Index	Daily	PM_{10}
Cambodia	—	—	—	—
PR China	Implemented	Air Quality Index	Hourly	SO_2, NO_2, PM_{10}, CO, O_3, $PM_{2.5}$
India	Proposed	Indian - Air Quality Index	Daily	SO_2, NO_2, SPM, CO, O_3, NH_3, $PM_{2.5}$, PM_{10}, Pb
Indonesia	Proposed	Indeks Standar Pencemar Udara/Pollution Standard Index	Daily	PM_{10}, SO_2, CO, O_3, NO_2
Lao PDR	—	—	—	—
Malaysia	Implemented	Air Pollution Index	4 hr	CO, O_3, SO_2, NO_2, PM_{10}
Myanmar	—	—	—	—
Nepal	—	—	—	—
Pakistan	Implemented but irregular	Air Quality Index	Daily (Irregular)	Includes PM_{10}, $PM_{2.5}$
Philippines	Established but not implemented	Air Quality Index	Daily	TSP, SO_2, CO, O_3, NO_2
Republic of Korea	Implemented	Community Air Quality Index	Hourly	SO_2, NO_2, CO, O_3, PM_{10}
Singapore	Implemented	Pollution Standard Index	daily, 3-hr	PM_{10}, SO_2, CO, O_3, NO_2
Sri Lanka	Established but not implemented	Sri Lanka Air Quality Index	Daily, Weekly	O_3, $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2
Thailand	Implemented	Air Quality Index	Running Mean Hourly for some stations, daily for others	PM_{10}, O_3, SO_2, NO_2, CO
Vietnam	Implemented	Air Quality Index	Hourly	Not indicated

Source: Clean Air Asia, 2013.

As illustrated in Figure 10, in Asia, air quality indexes may vary significantly from one country to another. Some of the key differences in different components are summarized below:

- **Pollutants Covered:** Most countries have indices on PM10, SO2, NO2, CO. Very few consider PM2.5
- **Bands:** Bands of the pollutant concentrations vary per country usually depending on their national ambient air quality standards
- **Frequency of Reporting:** Most report the index daily, with Beijing, Shanghai, Japan, and ROK reporting hourly
- **Reporting Area:** Mostly by stations but are also offered by region/district in some developed cities
- **Reporting Channels:** Mostly reported through websites but there are other countries which also include reporting through smart phone apps, social networks, newspapers, radio, and television
- **Text Descriptions:** Some countries base description on pollution levels (low, slightly polluted, high) while others base it on health impacts (low, unhealthy for sensitive groups, unhealthy, hazardous)

This may lead to some confusion by the public when looking at air quality indexes from different cities or countries, as was experienced in PR China. It may be useful to explore whether harmonization is possible in this region to avoid such confusion. While this will be challenging, especially because countries have different national air quality guidelines/standards, there may be merit in assessing the feasibility of a harmonization and identifying advantages and disadvantages.

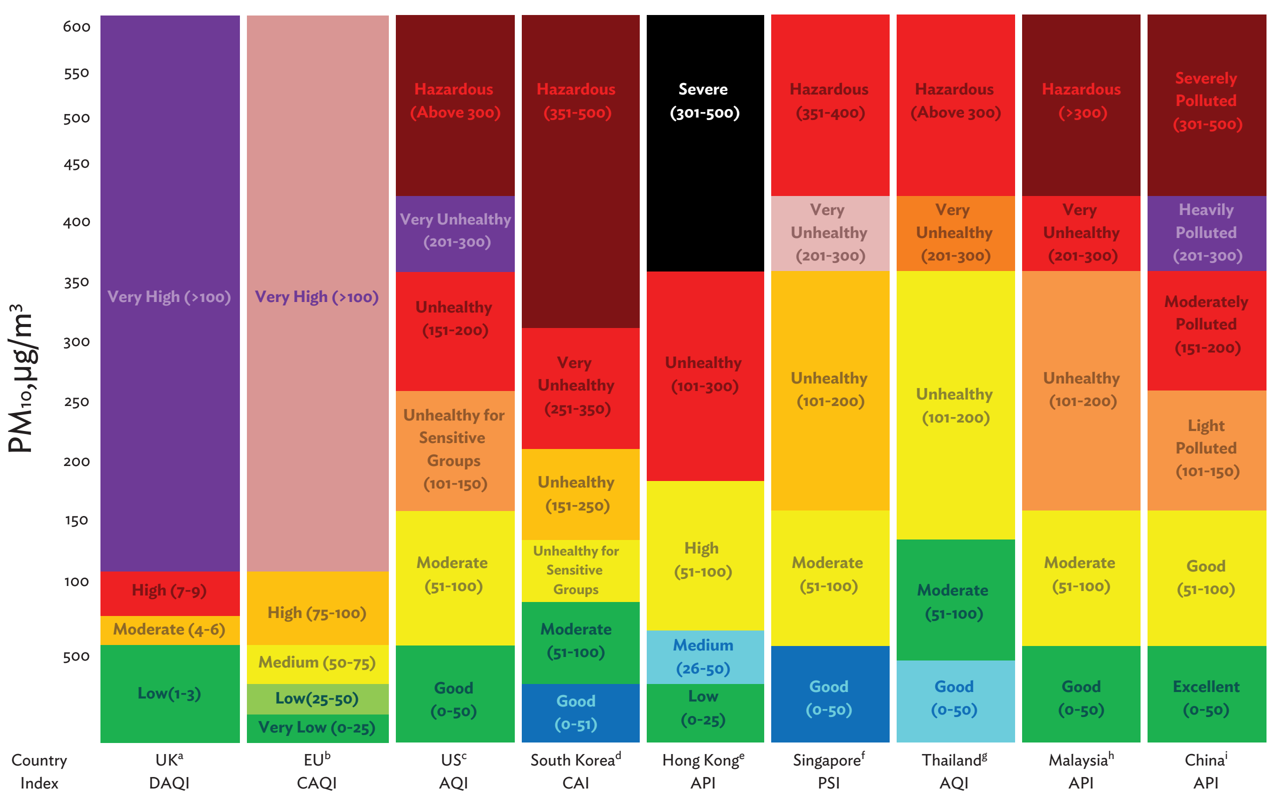


Figure 10. Comparison of PM10 AQI in selected countries

Source: Clean Air Asia, 2013.

In an effort to provide a comparative index which may be used to assess air quality levels, in 2010, the ADB and Clean Air Asia developed[12] the Clean Air Scorecard: an Excel-based tool incorporating three indices: (i) Air Pollution and Health, (ii) Clean Air Management Capacity, and (iii) Clean Air Policies and Actions, which are capable of identifying potential improvement areas for the city.

The Air Pollution and Health Index assess air pollution levels of cities against WHO guideline values and interim targets. A "good air" day in this index, then, is in relation to WHO guidelines rather than the city's ambient air quality standards, which are generally less stringent. This index includes seven pollutants (PM10, PM2.5, SO2, NO2, CO and Pb); a city is required to have, at a minimum, monitoring data for particulate matter with a diameter of 10 microns or less (PM10). The WHO guidelines and interim target-3 (IT-3) were considered as basis for the excellent category. Succeeding categories were based on interim targets 1 and 2 as well as annual average levels of Asian cities. [13]

The index is calculated for each pollutant separately and not as a composite index. For a city with data for different pollutants, the pollutant with the lowest score is considered the main pollutant of concern, and as such, the score considered in the computation of the city's overall clean air score is based on the pollutant with lowest score under the air pollution and health index. When comparing cities, however, it is required that the cities' air pollution and health indices be based on the same pollutant or set of pollutants. The score banding and description for each category are presented in Table 23. Since its development in 2010, the Clean Air Scorecard has been applied in 18 Asian cities in nine countries (Bac Ninh, Bangkok, Cagayan de Oro, Can Tho, Chiang Mai, Colombo, Foshan, Guangzhou, Hangzhou, Hanoi, Iloilo, Jakarta, Jinan, Kathmandu, Metro Manila, Quetta, Visakhapatnam, and Zhaoqiang). If ever this may considered as an option for the harmonization, the score bandings in the APHI may be converted to follow the same format as existing AQIs wherein poor air quality have high AQI values and good air quality have low AQI values.

Table 23. Score Bands and Category Descriptions for the Air Pollution and Health Index

Air Pollution and Health Index		
Category	**Score Band**	**Description**
Excellent	81–100	Low levels of pollution within WHO-prescribed guidelines. Public health implications for pollutants monitored are limited and hardly noticeable.
Good	61–80	Relatively low levels of air pollution but considerable impacts to sensitive groups.
Moderate	41–60	Elevated levels of air pollution with aggravated symptoms for sensitive groups and contributing to onset of risks for exposed healthy individuals.
Poor	21–40	High levels of pollution with significant health effects to vulnerable populations and contributing to increased risks for exposed healthy individuals.
Very Poor	11–20	Extremely high levels of pollution affecting large share of population.
Critical	1–10	Critical levels of air pollution resulting in adverse health effects to public in general.

Note: WHO = World Health Organization.
Source: Clean Air Asia, 2011.

[12] Clean Air Scorecard Tool Version 1 was developed under the Sustainable Urban Mobility in Asia (SUMA) program with support from Swedish International Development Cooperation Agency (Sida) and Asian Development Bank (ADB).

[13] For example, excellent is based on the WHO guideline of 20 µg/m3and interim target 3 of 30µg/m3. Good and moderate categories are based on the interim target 2 of 50 µg/m3 and the interim target 1 of 70 µg/m3, respectively. Poor and very poor categories are based on annual average PM_{10} of 101.23 µg/m3 in 180 cities in Asia and the standard deviation of 50 µg/m3.

Platforms to disseminate information

Choosing the platform to communicate air quality information is as important as choosing how the information is communicated. The table below shows the different platforms used in Asian cities to disseminate air quality information based on survey responses. Except for Colombo, the cities use several platforms to expand its reach.

Among the host of options, publishing online through website is the most preferred mode of information dissemination. It is followed by the publishing of reports and issuing of information upon request. The least used mode of information dissemination is broadcasting on television and publishing on print media. These trends in the choice of dissemination medium could be driven largely by their costs: online publishing is more popular because it is significantly cheaper than paying television and newspaper companies to share the information.

Several national and city governments utilized technology to better disseminate air quality information the public through mobile phone applications. For example, the Thailand PCD recently established Air4 Thai application which allows users to access air quality information in Bangkok and other areas in Thailand through their mobile phones. Publishing information online also increases the accessibility of information. Its success, however, is dependent on internet access and connectivity. This may become an issue for developing countries where a significant portion of the population has limited internet connection.

Table 24. Different platforms used for disseminating air quality information in Asian Cities

Cities	Web	Pub	Request	Print	TV	PubScr	Warnings
Bangladesh							
Chittagong	•	•	•				
Dhaka	•	•	•				
Radshahi	•	•	•				
Bhutan							
Thimphu	•		•		•	•	
India							
Delhi	•	•	•	•	•	•	•
Kochi	•	•				•	
Mumbai	•	•	•	•	•		•
Indonesia							
Jakarta	•	•	•			•	•
Japan							
Chiba	•	•	•	•		•	•
Fukuoka	•	•	•	•			
Hamamatsu	•	•	•			•	•
Hiroshima	•	•	•				
Kawasaki	•	•	•			•	•
Nagoya	•	•	•				
Sagamihara	•	•	•			•	•
Saitama	•	•	•				•
Sendai	•	•	•	•		•	•

Cities	Web	Pub	Request	Print	TV	PubScr	Warnings
Shizuoka	•		•	•			•
Tokyo	•	•	•				•
Mongolia							
Ulaanbaatar	•		•	•	•		
Nepal							
Kathmandu*							
Philippines							
Manila	•	•	•	•			
PR China							
Beijing	•	•	•		•	•	
Hangzhou	•	•	•		•		
Xian	•	•	•				
Republic of Korea							
Seoul	•	•	•	•	•	•	•
Singapore							
Singapore	•	•	•	•	•		•
Sri Lanka							
Colombo			•				
Thailand							
Bangkok	•	•	•	•		•	•
Rayong	•	•	•	•		•	•
Vietnam							
Hanoi		•	•			•	•

*Stations were not operating.
"Web" – i nformation is published in websites or made available in online data banks.
"Pub" – publications (e.g. annual reports).
"Request – data is released upon personal request (usually written communication).
"Print – publishing in print media like newspapers.
"TV – broadcasted on television.
"PubScr – screening on public information boards.
"Warnings" –issuance of advisories during pollution episodes.
Note: THA = Thailand; PRC = People's Republic of China; JAP = Japan; BAN = Bangladesh; SRI = Sri Lanka; IND = India; VIE = Vietnam; INO = Indonesia; NEP = Nepal; PHI = Philippines; ROK = Republic of Korea; SIN = Singapore; BHU = Bhutan; MON = Mongolia.
Source: Authors, based on responses from survey of monitoring stations.

Reliance on printed reports likewise raises concerns on the adequacy of printed copies and its distribution. Limited public screenings and issuance of public warnings may also be an indication that the infrastructure for information dissemination for short-term pollution episodes is not yet well-developed. This is a good avenue for improvement because aside from protective measures taken at the level of the individual during pollution episodes, the information could also be used as a basis for short-term mitigation actions like limiting the number of vehicles plying the roads during pollution episodes (Atmo France, 2011). An example of this is the Emergency Response Plan for Heavy Air Pollution developed by the Beijing Environmental Protection Bureau in January 2013 in light of air pollution episodes in the city. The plan included measures to be implemented at different pollution levels. For instance, the key measures for extreme pollution levels (AQI>500) include:[14]

- Required heavy polluting enterprises to reduce emission by 30%. Construction was suspended at 28 construction sites and 54 businesses reduced their emissions by 30%.
- Required 30% of vehicles owned by the government agencies and government affiliated institutes to stop running on the road, and provide more public transport in the mean time.
- Outdoor sports activities for primary and middle schools were ordered to be halted from Sunday to Tuesday in extreme pollution areas, including Tongzhou, Miyun, Daxing, Mentougou and Fangshan districts.
- Suggestions provided to the public: do not go out unless necessary; wear masks when going out; and vulnerable groups such as elders, minors and people with chronic disease should see doctors if feeling uncomfortable.
- Fourteen inspection teams were dispatched to 14 districts and counties to oversee the pollution-reduction measures.

In some cities like Hanoi, the organizations responsible for monitoring air quality are different from those that are responsible for disseminating information which leads to infrequent information sharing. Also, in instances of equipment failures whereby data collected may be unreliable, the data are nevertheless forwarded to the other organization that is tasked to share the information. Monitoring systems employing a similar arrangement, therefore, must be integrated whereby all the organizations that are involved communicate and collaborate with each other to increase both the reach and reliability of the information being shared.

[14] Clean Air Asia prepared a press release on this information. See: http://cleanairinitiative.org/portal/node/11599
[15] For more information about Shanghai AIRNow-I Program, see link: http://megaevents.cleanairinitiative.org/shanghaiexpo2010

2.5.3 Case Studies: Good Practices in Asia

Case Study 1: Using mega-events to leapfrog air quality management in Shanghai

The Situation: Mega-events are major events that draw both local and international crowd, often in millions, into a host city that showcases its culture, people, products, and services. Mega-events also provide a unique opportunity to advocate policies that improve air quality during and after the duration of the mega-event. The World Expo 2010 that was hosted by Shanghai was such an event that called for an effective air quality monitoring system. The challenge was to adopt a more comprehensive monitoring system and to disseminate real-time data to the public. Prior to this, Shanghai only provided only PM10, SO2 and NO2 data and API were made available to the public.

The Response: On April 2010, the Shanghai Environmental Protection Bureau (SEPB) and the US Environmental Protection Agency collaborated on the 'Shanghai Environmental Air Quality Dynamic System' (AIRNow-I) program. This initiative built on Shanghai's existing air quality monitoring network and capability in analyzing air quality data. The AirNow-I system provided real-time air quality reporting from the World Expo 2010 and sent out through the internet.[15]

On February 2012, the country adopted new ambient air quality standards that are comparable to the interim targets set by the WHO, specifically, Grade II PM2.5, PM10 and O3 (8-hour) standards. The SEPB and the Shanghai Environmental Monitoring Center, building on the AirNow-I system, further improved the air quality information shared to the public–moving from API to AQI. In addition, in December 2012, they launched a new mascot as part of its efforts to improve communication of air quality information to the public. The mascot, which is called an air quality baby, illustrates the real-time air quality situation in the city (Figure 11). The air quality index is made available through the SEMC website and shows the hourly updates from different monitoring stations in Shanghai including the concentrations per pollutant. The air quality index is also available through micro blogs, TV news, newspapers, and app software (Figure 12).

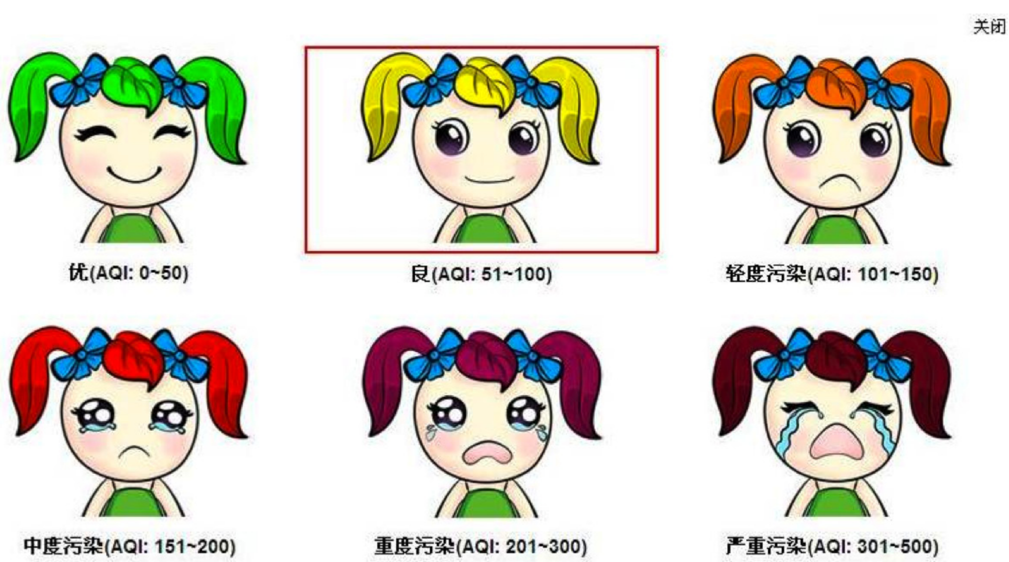


Figure 11. Shanghai air quality baby depicting the air quality situation in the city

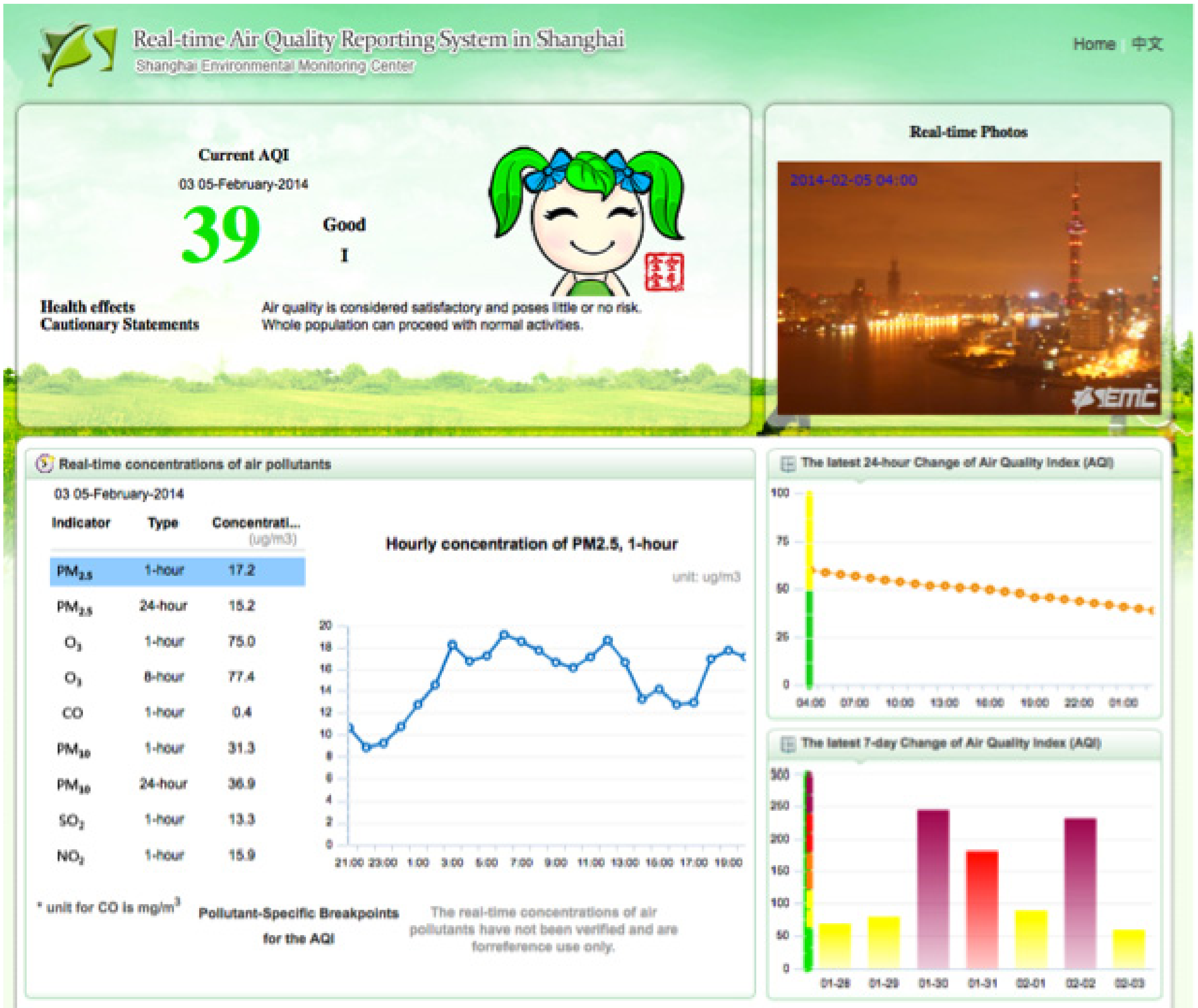


Figure 12. The air quality index in different media platforms

Source: http://www.semc.gov.cn/aqi .

Case Study 2: Creative presentation of air quality information to the public in Hong Kong SAR

The Situation: Protecting public health is the foremost objective of air quality management. Keeping the public informed on how pollution levels affect their health and general well-being is important in achieving that goal because it allows them to take precautionary measures during pollution episodes. It also increases their involvement in efforts to keep pollution levels low. However, majority of Asian cities communicate air pollution as concentrations and, to a limited extent, as air quality indexes, which may not be fully understood by the general public. The challenge, therefore, is to communicate air quality data in a manner that is simple and easily understood by the public.

The Response: The Hedley Environmental Index (HEI) developed by Civic Exchange in collaboration with Stuart Judge Gill Ltd., with the support of Fu Tak Iam (FTI) Foundation is a novel approach to health risk communication because it transforms data on pollution levels into concrete impacts to human health and the equivalent economic costs. This, along with the visual representation of the information, enables the public to better understand and act on the problem. Given the widespread use of the internet, the availability of the HEI online as well as a sharing option on Facebook® (a popular social networking site) also increases its accessibility. Shown below are the components of the HEI. It has a real-time air quality meter based on guidelines set by the WHO, and a real-time air pollution map based on data from different monitoring stations all over Hong Kong. It also has monthly and annual pollution reports expressed as “clear” and “exceedance” days relative to the WHO short-term guideline. The impacts of air quality on human health are also shown as avoidable premature deaths, bed days, and doctor visits. The burden of disease and lost productivity expressed in terms of economic losses are likewise shown. The index was first launched in 2008 containing health and economic impacts and the monthly pollution reports. The real-time pollution meter and pollution map was added when it was revised in January 2012.

Figure 13. The components of the HEI Index used to communicate air quality information in Hong Kong

Source: http://hedleyindex.sph.hku.hk/html/en/ .

Case Study 3: Adapting to public demand for air quality information in Singapore

The Situation: Like other aspects of air quality monitoring, reporting air quality information must also be dynamic not only in response to the changes in the emission profile of an area but also to the changes in the demand for information. The case of Singapore and how it manages haze episodes is a good illustration of the importance of reporting flexibility to manage and respond to air quality problems. Singapore often suffers from haze episodes that are caused by forest fires and unfavorable meteorological conditions (NEA, 2013). Only recently, Singapore experienced one of its worst haze episodes causing the Pollution Standard Index (PSI) to soar to 401 – the highest level recorded thus far (Shukman, 2013). Prior to August 2012, Singapore's National Environment Agency (NEA) only reports its PSI once a day for each of its five regions, East, West, North, South, and Central. Health advisories that are not differentiated per region are also only issued when the air quality deteriorates to unhealthy levels (PSI < 100). The demand, however, for better reporting rose as the haze episodes became more frequent.

The Response: After August 2012, reporting of PSI became more frequent; from once to thrice daily – 8am, 12 noon, and 6pm (Figure 14). The issuance of health advisories were likewise made to coincide with the PSI reports. It was also made specific to each of the five regions in Singapore. The NEA also formulated a communication and action plan (Table 25) to better manage the haze episodes both at the level of the individual through early warning systems and better information dissemination, and at the level of the government and industries in implementing measures to reduce emissions.

Table 25. Singapore's action plan for haze episodes

PSI Value	Communication	Actions
Up to 50	• PSI updates to other ministries and agencies so that they can get ready to implement their Standard Operating Procedures (SOPs).	• Liaise with industries with fuel-burning equipment on the need to cut down emissions • Liaise with major vehicle fleet owners on measures to minimize emissions
50 to 100	• Same as above	• Same as above
101 to 200	• Provide hourly PSI updates and health advisories Activate Haze Info-line (1800-7319222) • Haze Task Force to hold press briefings	• When 24-hour PSI stays above 100 for more than 48 hours, Haze Task Force to meet as often as required to coordinate implementation of the SOPs of individual ministries and agencies.
201 to 300	• Same as above	• Same as above
301 to 400	• Provide regular updates on the haze situation to the public. • Haze Task Force to hold press briefings	• Inform industries and major vehicle fleet owners to cut down emissions • Advise reducing use of private motor vehicles • When 24-hour PSI>250, Haze Task Force to meet to reaffirm measures advising industries, construction sites, etc., on outdoor work, closure of schools, stoppage of outdoor functions and sports activities
Over 400	• When 24-hour PSI>350, deliberate need to declare a haze emergency if PSI exceeds 400 • Haze Task Force to hold press briefings	• Convene urgent meeting to decide: - closure of schools; childcare centers; sports facilities - cancelling outdoor work by industries, construction sites, etc., and/or use of respirators by workers doing outdoor work

Source: NEA.gov.sg.

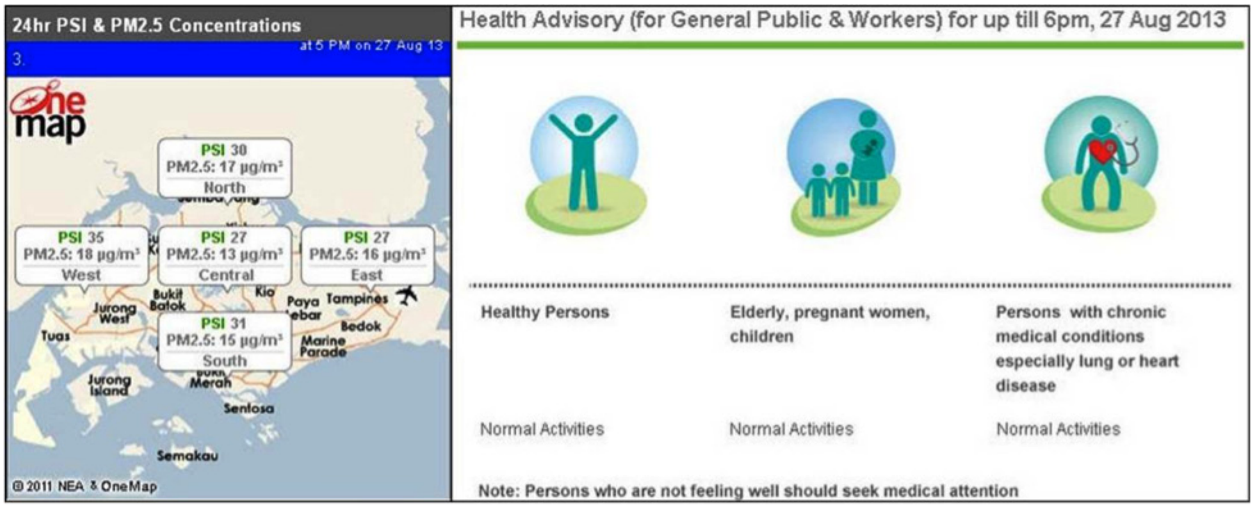


Figure 14. Enhanced reporting of air quality information in Singapore

Source: http://www.haze.gov.sg/Home.aspx .

2.6 Characteristic 5: Effective communication of air quality information to policy and decision-makers

2.6.1 International Good Practice

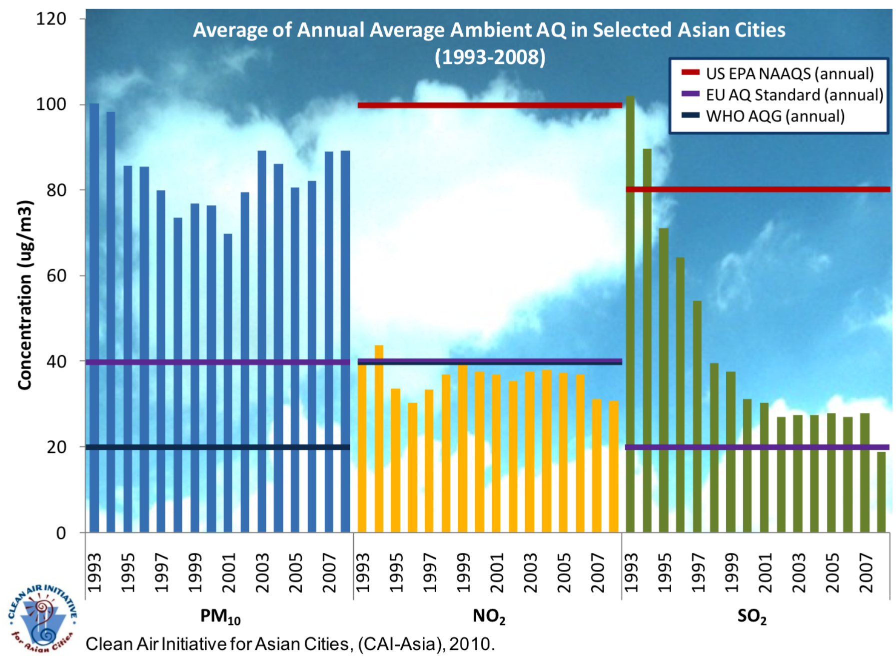
Policy and decision makers, being the ones responsible for crafting legislation, are integral in improving air pollution control policies. However, they may not have the necessary background to understand and appreciate raw information on air pollutant concentrations, dose-response, and emissions inventories. They may likewise not have time to pore over lengthy reports because they are often preoccupied with a multitude of concerns continuously competing for their attention. Given these, for air quality to be included in the policy agenda, information must be framed in such a way that will be relevant to, and understood by policymakers.

The issue of air pollution, therefore, will gain more traction if it is presented simply and concisely. It is also ideal to provide concrete interventions or recommendations and the trade-offs involved in pursuing a certain plan of action. It is imporant to incorporate cost benefit analysis as decision makers best understand and respond based on monetary evaluations. Guidance on cost benefit analysis of air quality related issues for Europe is available (AEA Technology Environment, 2005).

Relating the problem with other development challenges like climate change, energy use and security, and transportation will likewise increase its chances of gaining attention. Listed below are examples of commonly used tools for communicating the information to policymakers. Figures 15a and 15b also provide some examples of these options.

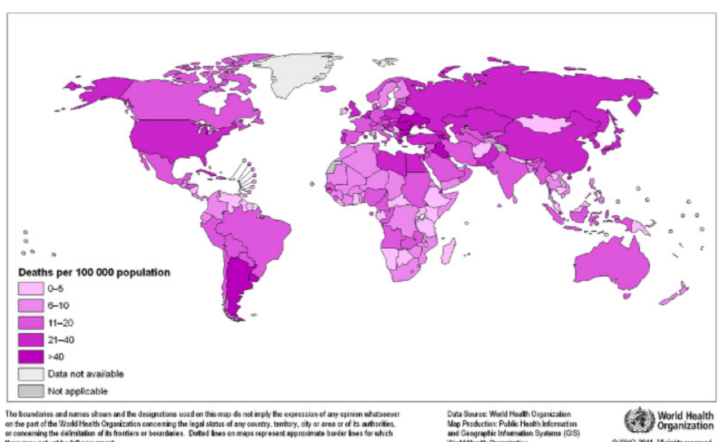
- Policy briefs
- Written reports
- Summary tables
- Visual presentations
- Interpretation of information
- Pie chart and map
- Satellite imagery

The ultimate indicator of how well an issue is communicated to the policymakers is the adoption and implementation of legislation or other control measures to address the issue. In air quality management, the passage of ambient air quality standards and laws that limit emissions from vehicles as well provide budgetary and logistical support for monitoring systems are concrete indicators of the relative success of the efforts communicate and use monitoring information to shape policies.



Clean Air Asia, (2010)

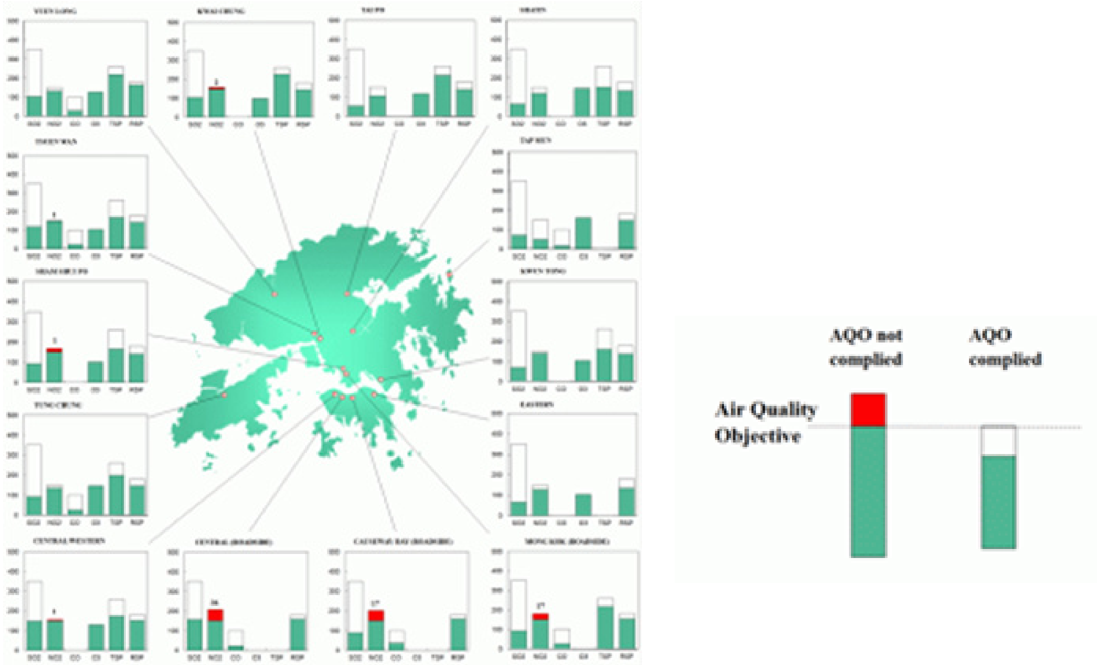
Interpreted Data



Deaths attributable to outdoor air pollution, WHO, 2004

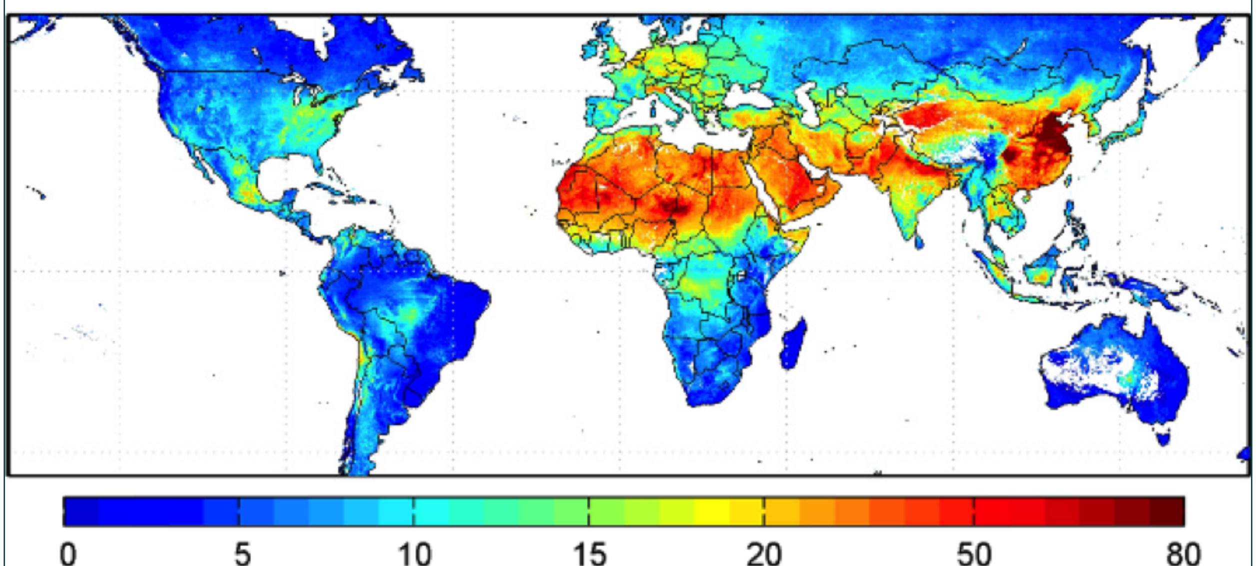
Visual Presentations

Figure 15a. Examples of commonly used tools for communicating the information to policymakers: Interpreted data and visual presentation



Hong Kong: Maximum Daily Pollutant Concentrations and Objectives in 2008
HK EPD, 2008

Interpreted Data



Global satellite-derived map of PM2.5 averaged over 2001-2006 (μg/m3)
NASA, 2010

Satellite Imagery

Source: Clean Air Asia, 2012.

Figure 15b. Examples of commonly used tools for communicating the information to policymakers: Maps, pie charts and satellite imagery

Status reports are a good avenue for communicating relevant information to policymakers because they comprehensively document in a concise manner the state of the problem, its causes, and the possible actions that can be undertaken to address the problem. Hence, this section uses the national air quality status reports published by countries as an indicator of how well monitoring information is utilized to improve air quality policy. Countries either publish such reports singly or as a part of a more comprehensive national environment report. Listed below are components that can be typically found in an air quality status report:

- Summary of the extent of air pollution (disaggregated per type of pollutant and source)
- Analysis of the state of pollution and pollution trends
- Identification of critical areas or projects in need of closer monitoring and support
- Concrete recommendations to the legislative and executive bodies of the government in improving air quality management
- Identification of relevant information (both qualitative and quantitative) regarding the contribution of industries and transport to air pollution

2.6.2 Status and Challenges in Asia

One of the key challenges in Asia is to be able to use air quality monitoring results to improve air pollution control policy. For this to happen, it is necessary that ambient air quality standards exist, air quality monitoring is conducted and comparisons againt the standard to benchmark success of policies and measures to address air pollution issues. The current situtation in Asia for PM2.5 is provided in Table 26. It is observed that in some countries there are no PM2.5 standard. In some countries where there are standards, PM2.5 is not yet monitored.

Table 26. PM2.5 standards, monitoring and reporting in selected Asian countries

Countries	$PM_{2.5}$ standards	Monitoring	Reporting (Public)
Afghanistan			
Bangladesh	•		
Bhutan			
Brunei Darussalam			
Cambodia			
PR China	•	•	•
Hong Kong SAR		•	•
India	•		
Indonesia	•	•	•
Japan	•	•	•
Malaysia			
Mongolia	•	•	•
Myanmar			
Nepal			
Pakistan	•		
Philippines	•	•	
Republic of Korea			
Singapore	•	•	•
Sri Lanka	•		
Thailand	•	•	•
Viet Nam	•	•	•

Note: Others may also monitor, but for research purposes only.
Source: Updated from Clean Air Asia, 2011.

Table 27 shows the characteristics of air quality status reports in selected Asian countries. From the table, it can be observed that most of the reports focus heavily on data analysis. While useful, it overlooks other aspects of air quality management such as the health and socio-economic impacts of pollution levels, as well as the possible measures to mitigate the impacts. It likewise leaves out which areas need to be prioritized and the concrete steps that need to be undertaken to improve air quality. Such deficiencies are missed opportunities because the aforementioned components are integral to making the policymakers understand and act on the issue. The same set of information is likewise important because they form the basis for formulating sound policies.

In some countries, sporadic or late issuance of reports is also a concern. This situation presents opportunities for improving the content of the status report and its utility. From the same table, it can be observed that most countries issue their air status reports in their own language. This is commendable because it makes the information more accessible and understandable. All the countries covered in the survey also have adopted their own national air quality standards - a basic, albeit limited, indicator that the issue on air quality is in the policy sphere.

Generally, it is recommended that in developing either a country or city air quality report that the following objectives are kept in mind:

- Provide a complete picture of air quality management in a city;
- Compile air quality management information useful for policy and decision makers, researchers and the general public;
- Allow analysis of AQM challenges and determine areas for improvement, not only on compliance side, but also in terms of implementation, institutional arrangements and others;
- Allow residents to appreciate achievements in improving air quality; and
- Provide guidance (by proposing priority areas/measures).

Table 27. Characteristics of air quality status reports in Asia

Country/ City	Title	Lead Organization	Frequency	Most Recent Version	Contents	Status/ Remarks	Link
India	National Ambient Air Quality Status Report	CPCB	Annual	2010	• Air quality monitoring system information • Air quality assessment (for one year): General and pollutant specific (SO_2, NO_2, SPM, PM_{10} and others) • Air quality trends • Initiatives for air pollution control	2010 version published in January 2012	http://cpcb.nic.in/upload/NewItems/NewItem_192_NAAQSTI.pdf
Hong Kong	Air Quality in Hong Kong	EPD	Annual	2012	• Air quality monitoring results for current year for gaseous pollutants, suspended particulates and toxic air pollutants • Variation of air pollution levels over time (diurnal, seasonal, long-term)	Regularly prepared and published	http://www.aqhi.gov.hk/en/download/air-quality-report-se469.html?showall=&start=1html?showall=&start=1
Philippines	National Air Quality Status Report	EMB	Every two years	2005-2007	• Sources of air pollution • Status of ambient air quality • Air quality management (by source and by organization) • Best practices and lessons learned • Challenges and recommendations	Report for 2010-2011, and 2012 under preparation	http://emb.gov.ph/eeid/publications.htm
Republic of Korea	Annual Report of Air Quality in Korea (in Korean)	MOE	Annual	2012	• Air quality status and volume of emissions	Regularly prepared and published but only available in Korean	http://stat.me.go.kr/nesis/mesp/knowledge/MorgueStatistical.do?task=I&leftMenu=knowledge&page_code=P3_05
Thailand	Thailand's Air & Noise Status and Management (in Thai	PCD	Annual	2012	• Air quality status and volume of emissions • Measures on prevention and control of air & noise pollution with focus chapters on key sources (industry/vehicles) • Public awareness campaigns	Regularly prepared and published but only available in Thai	http://www.pcd.go.th/download/en_air.cfm

Country/City	Title	Lead Organization	Frequency	Most Recent Version	Contents	Status/ Remarks	Link
PR China	As part of: State of the Environment in China	MEP	Annual	2012	• Reduction of total discharge of major pollutants • Atmospheric environment: status of air quality (by pollutant), acid rain frequency and distribution, emissions estimates and measures and actions • State of water, marine, acoustic, solid waste, radiation, nature and ecology, land and rural environment, forest, grassland, climate and natural disasters, • Environmental management	Regularly prepared and published (in Chinese and English)	http://english.mep.gov.cn/standards_reports/soe/
	State of 74 Cities Air Quality	MEP	Annual	2014	• Air Quality: monthly aveage concentration of pollutants. pollutants and cities of concern	Regularly prepared and published (in Chinese and English)	http://www.cnemc.cn/publish/totalWebSite/news/news_40273.html
Malaysia	As part of: Malaysia Environmental Quality Report	DOE	Annual	2012	• Air Quality: monitoring, current status and trends • River, ground and marine water quality • Pollution sources inventory	Regularly prepared and published	http://www.doe.gov.my/webportal/en/penerbitan-jas/
Viet Nam	As part of: National Environmental Report (in Vietnamese)	VEA	Annual	2012	• Economic development activities, changes in climate and other environmental pressures • State of environment quality of soil, water and air • Special focus on solid waste and biodiversity • Impacts of environmental pollution • State of environmental management • Proposed measures	Regularly prepared and published but only available in Viet Namese (except for 2007). Each year has a different theme. 2012focused on surface but 2013 will focus on air environment.	http://vea.gov.vn/vn/hientrangmoitruong/baocaomtquocgia/Pages/default.aspx

*online/ published | Notes: CPCB = Central Pollution Control Board; EPD = Environmental Protection Department; EMB = Environmental Management Bureau; MOE = Ministry of Environment; PCD = Pollution Control Department; MEP = Ministry of Environmental Protection; DOE = Department of Environment.
VEA = Viet Nam Environment Administration. Source: Updated from Clean Air Asia, 2012.

2.6.2 Status and Challenges in Asia

Case Study 1: Using clean air reports to support policy development in Viet Nam

The Situation: In 2007, the Ministry of Natural Resources and Environment (MONRE) developed the first Viet Nam State of Environment Report which focused on urban air environment because this is an emerging concern in urban centers in Viet Nam in recent years. The report provided an overview of the current status and trends of air pollution, an assessment of the sources and its impacts, and stated concrete recommendations to improve air quality management for the country. One of the key recommendations from this report is to set up a unit within MONRE who will be responsible for air quality management at the national level.

The Response: On 4 March 2008, the Prime Minister issued a decree (No. 25/2008/ND-CP) mandating the functions, tasks, powers, and the new organizational structure of MONRE. The decree upgrades the former Viet Nam Environment Protection Agency of MONRE to the Viet Nam Environment Administration (VEA) which will function like a small ministry within MONRE with its own departments (including an international department), institutes, and centers. In 30 September 2008, the Prime Minister issued Decision No. 132/2008/QD-TTg defining the functions, tasks, powers, and organizational structure of the VEA.

Under this decision, the VEA acts as a subsidiary body under MONRE and functions to advise and assist MONRE in the field of state management of environment and to provide public services in compliance with the laws.

One of the key departments within VEA is the **Department of Pollution Control** which focuses on the control, prevention, and reduction of environmental pollution on soil, water, and air, management of hazardous chemicals, and prevention, response, and mitigation of environmental pollution/contamination caused by natural disasters or environmental accidents. Within this department is the **Pollution Control Division for Air, Recycling materials and Toxic Releases** which specifically works on addressing AQM issues at the national level.

Case Study 2: Improving air quality standards in Singapore based on monitoring data and international air quality benchmarks

The Situation: For several years, Singapore has adopted the Pollutant Standards Index (PSI) based on SO2, PM10, Ozone, NO2 and CO as the basis for reporting daily air quality levels. Air quality monitoring results show that air quality in Singapore has been improving: air quality within 'Good' range 96% of the time in 2011 compared to 82% in 2000. Although Singapore's air quality has improved, the WHO air quality guidelines to assess air quality have become more stringent. Before the WHO (2005) update, Singapore was able to meet the WHO AQGs. Compared with the updated guidelines in 2005, Singapore can only meet the final AQGs for NO2 and CO and the interim targets for PM2.5.

The Response: The National Environment Agency (NEA) formed an Inter-Agency Advisory Committee on Ambient Air quality in July 2010 to advice on a set of air quality targets for Singapore to safeguard public health. In July 2011, the committee shared its recommendations based on an assessment that WHO AQGs are internationally recognized and rigorous as they are backed by scientific findings and health studies. The new air quality targets were announced in August 2012, in line with the WHO AQGs and with the Sustainable Singapore Blueprint launched in 2009 (see table below).

In addition, NEA developed a roadmap with a set of emissions reduction measures to meet their 2020 targets, and achieve sustainable growth and development while maintaining public health and economic competitiveness.

Table 28. Singapore Ambient Air Quality Targets

Pollutant	Singapore Targets (By 2020)	Long Term Targets
Sulfur dioxide (SO_2)	24-hour mean : 50 µg/m^3 (WHO Interim Target) Annual mean : 15 µg/m^3 (Sustainable Singapore Blueprint)	24-hour mean : 20 µg/m^3 (WHO AQG Final)
$PM_{2.5}$	Annual mean: 12 µg/m^3 (Sustainable Singapore Blueprint) 24-hour mean: 37.5 µg/m^3 (WHO Interim Target)	Annual mean: 10 µg/m^3 24-hour mean: 25 µg/m^3 (WHO AQG Final)
PM_{10}	Annual mean: 20 µg/m^3 24-hour mean: 50 µg/m^3 (WHO AQG Final)	
Ozone	8-hour mean: 100 µg/m^3 (WHO AQG Final)	
Nitrogen dioxide (NO_2)	Annual mean: 40 µg/m^3 1-hour mean: 200 µg/m^3 (WHO AQG Final)	
Carbon monoxide (CO)	8-hour mean: 10 mg/m^3 1-hour mean: 30 mg/m^3 (WHO AQG Final)	

Source: NEA.gov.sghttp://app2.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/air-quality-and-targets.

3. REFERENCES

ADB. (2010). Key Indicators for Asia and the Pacific: 41st Edition. Mandaluyong City: Asian Development Bank.

AEA Technology Environment. (2005). Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme.
http://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol1.pdf
http://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol2.pdf

Aerosol and Particulate Research Lab - University of Florida. (2013). Air Quality Monitoring. Retrieved from Elements of Air Pollution (ENV 4101/5105): www.essie.ufl.edu/~cywu/env4101/Air%20Quality%20Monitoring.ppt

Atmo France. (2011). International comparison of air quality monitoring systems (p. 50). Retrieved from http://www.airparif.asso.fr/_pdf/publications/comparaison-internationale-atmofrance-en.pdf

Bitterman, J. (2010). Balloon helps Parisians breathe easy. CNN. Retrieved from http://edition.cnn.com/2010/WORLD/europe/09/19/paris.balloon.air.quality/

Chow, J., Watson, J., & Tropp, R. (2012). Technical Challenges in Air Quality Monitoring: Quality Control and Quality Assurance. Presented at Better Air Quality Symposium on Improving Air Quality Monitoring Systems in Asia . Hong Kong SAR.

Clean Air Asia. (2010). Real-time air quality information and forecast. Retrieved from http://megaevents.cleanairinitiative.org/shanghaiexpo2010/airqualityreporting

Clean Air Asia. (2011). Status and Trends in Air Quality Management. Pasig City, Philippines. http://cleanairinitiative.org/portal/node/3962

Clean Air Asia. (2012). Clean Air Reporting by Cities: Guidelines and China Case Studies. http://cleanairinitiative.org/portal/sites/default/files/Guidelines_of_How_to_Develop_CCAR.pdf

DENR EMB. (1999). Philippine Clean Air Act of 1999 (Republic Act 8749). Retrieved from:http://www.emb.gov.ph/mmairshed/Policies/ra8749-clean%20air%20act.pdf

Department of Motor Traffic. (2011). Vehicle Emission Testing. Retrieved from Department of Motor Traffic, Government of Sri Lanka: http://www.motortraffic.gov.lk/web/index.php?option=com_content&view=article&id=123%3Avehicle-emission-testing-&Itemid=149&lang=en

EEA. (2013). Air Implementation Pilot: Lessons learnt from the implementation of air quality legislation at urban level. EEA Report No 7/2013. Retrieved from:http://www.eea.europa.eu/publications/air-implementation-pilot-2013

Environment Canada. (2004). National Air Pollution Surveillance Network Quality Assurance and Quality Control Guidelines (p. 44). Ottawa. Retrieved from http://www.etc-cte.ec.gc.ca/publications/naps/NAPSQAQC.pdf

EPD. (2006). API and Air Monitoring Background Information. Retrieved from Environmental Protection Department, The Government of Hong Kong Special Administrative Region: http://www.epd-asg.gov.hk/english/backgd/table122.html

EPD. (2009). Air Quality Status Reports in Hong Kong. Retrieved from Environmental Protection Department, The Government of Hong Kong Special Administrative Region: : http://www.aqhi.gov.hk/en/download/air-quality-reportse469.html?showall=&start=1

European Union (EU). (2004). Directive 2004/107/EC of the European Parliament and of the Council Related to Arsenic, Cadmium, Mercury, Nickel and Polycyclic Aromatic Hydrocarbons in Ambient Air

European Union (EU). (2008). Directive 2008/50/EC of the European Parliament and of the Council on Ambient Air Quality and Cleaner Air for Europe. Official Journal of the European Union

Grimm H., Eatough D.J., (2009) "Aerosol Measurement: The Use of Optical Light Scattering for the Determination of Particulate Size Distribution, and Particulate Mass, Including the Semi-Volatile Fraction". J. Air & Waste Manage. Assoc. 59:101–107

Haq, G. & Schwela, D. (2008). Monitoring: Foundation Course on Air Quality Management in Asia. Stockholm. Retrieved from: http://www.sei.se/cleanair

Hsu, A. & Miao, W. (2013). Beyond 'Crazy Bad': Explaining Beijing's Extreme Air Pollution. Retrieved from http://environment.yale.edu/envirocenter/post/beyond-crazy-bad-explaining-beijings-extreme-air-pollution/

Hunter, A.J.R., Fraser M. E., Davis, S.J. "Real Time Monitoring of Airborne Metals," SPIE Paper No. 3534 34, presented at Environmental Monitoring and Remediation Technologies (Boston, MA, 1-6 November 1998), SPIE 3534, 262-70 (1999).

Johnson K. S., Laskin A., et al., (2008) "Comparative Analysis of Urban Atmospheric Aerosol by Particle-Induced X-ray Emission (PIXE), Proton Elastic Scattering Analysis (PESA), and Aerosol Mass Spectrometry (AMS)", Environ. Sci. Technol. 42, 6619–6624

Kidwell C. B., Ondov J. M., (2011) Elemental Analysis of Sub-hourly Ambient Aerosol Collections. Aerosol Science and Technology, 38:3, 205-218

Lim, S. et al. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis of the Global Burden of Diseease Study 2010. Lancet , 380, 2224-2260.

Ministry for the Environment New Zealand (2002). Ambient Air Quality Guidelines. Retrieved from http://www.mfe.govt.nz/publications/air/ambient-air-quality-may02/ambient-guide-may02.pdf

NEA. (2012). Air Quality and Targets. Retrieved from National Environment Agency: http://app2.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/air-quality-and-targets

NEA. (2013). Haze. Retrieved from National Environment Agency: http://app2.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/hazeObservatoire Atmospherique Generali. (n.d.). La Couleur: Pourquoi le ballon change-t-il de coloeur? Retrieved August 2013, 2013, from Ballon de Paris: http://www.ballondeparis.com/fr/ballondeparis/i12-la-couleur

Observatoire Atmospheric Generali. (nd). Ballon de Paris. Retrieved from http://www.ballondeparis.com/fr/#

Perera, Q. (2007). Sri Lanka: Vehicle Emission Testing programme. Retrieved from Asian Trbune: http://www.asiantribune.com/node/8312

Parshintsev J., et al., (2009), "Analysis of organic compounds in ambient aerosols collected with the particle-into-liquid sampler". Boreal environment research 14: 630–640

Quirit, L., et al (2006). Comparison of Several Methods for Nitrogen Dioxide and Sulfur Dioxide in Metro Manila Air. University of the Philippines.

Singapore Government. (2014). Haze Situation Update. Retrieved from http://www.haze.gov.sg/Home.aspx

Schwela, D. (2009). Air Quality Management. in Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities (module 5a).

Schwela, D. (2010). GAP Forum Air Pollution Monitoring Manual. Stockholm. Retrieved from http://www.sei-international.org/rapidc/gapforum/html/technical/monitoring/GAP_Forum_Monitoring_Manual_2010.pdf

Shanghai Environmental Monitoring Center. (n.d.). Real Time Air Quality Reporting System in Shanghai. Retrieved from http://www.semc.gov.cn/aqi/home/English.aspx

Shukman, D. (2013). Singapore haze hits record high from Indonesia fires. Retrieved from BBC News Asia: http://www.bbc.co.uk/news/world-asia-22998592

Sivertsen, B. (2002). Air Quality Monitoring Program Design (p. 28). Kjeller, Norway.

Solon, O. (2011). Seoul sculpture shares real-time air quality data. Retrievedfrom Wired: http://www.wired.co.uk/news/archive/2011-01/25/seoul-living-light-air-quality

Stockholm Environment Institute (SEI) & Korea Environment Institute (KEI). (2004). A Strategic Framework for Air Quality Management in Asia. Retrieved from http://www.unep.org/PDF/APMA_strategic_framework.pdf

Suwanathada, P. (2012). Sustaining Thailand Air Quality Monitoring System. Presented at . Hong Kong SAR.

Swiss-Vietnamese Clean Air Program (SVCAP), 2007. "Report on the first Air Quality Measuring Campaign in Hanoi using the Passive Sampling Method." SVCAP Phase I: Database Component Subcomponent 1.3: Passive Sampling.

UN ECE. (2009). Guidelines for Developing National Strategies to Use Air Quality Monitoring as an Environmental Policy Tool (pp. 1–19). Retrieved from http://www.unece.org/fileadmin/DAM/env/europe/monitoring/Publications/Air_and_Water_Quality_Monitoring/documents/ECE-CEP-168-EN_for_DNS_CLEAN.pdf

UNEP & WHO. (1995). GEMS/AIR Methodology Reviews Vol 5: Guidelines for GEMS/AIR Collaborative Reviews. Nairobi. Retrieved from http://libdoc.who.int/hq/1995/WHO_UNEP_1995.pdf

University of Hongkong. (2012). Hedley Environmental Index. Retrieved from http://hedleyindex.sph.hku.hk/html/en/

US EPA. (1994). Quality Assurance Handbook for Air Pollution Systems - Volume I: A Field Guide to Environmental Quality Assurance (Vol. I, p. 54). Retrieved from http://www.epa.gov/ttnamti1/files/ambient/qaqc/r94-038a.pdf
US EPA. (1999a) Compendium Methods for the determination of Inorganic Compounds in Ambient Air. Methods IO-1.1 to IO-2.4. Retrieved from http://www.epa.gov/ttnamti1/inorg.html
US EPA. (1999a). Air quality index reporting (40 CFR Part 58). Federal Register Envi- ronmental Documents 64 (149)http://www.law.cornell.edu/cfr/text/40/part-58/appendix-D
US EPA. (2000). EPA Fact Sheet: The National Ambient Air Monitoring Strategy. Retrieved from http://www.epa.gov/ttnamti1/files/ambient/monitorstrat/fact.pdf
US EPA. (2005). National Ambient Air Monitoring Strategy (p. 125). Retrieved from http://www.epa.gov/ttn/amtic
US EPA. (2006). Guidelines for the Reporting of Daily Air Quality - the Air Quality Index. Retrieved from US EPA Technology Transfer Network: http://www.epa.gov/ttn/oarpg/t1/memoranda/rg701.pdf
US EPA. (2010). AIRNow International Launch at Shanghai Expo. Retrieved from http://www.epa.gov/oita/regions/Asia/china/airnowi.html
US EPA. (2013a). Quality Assurance Handbook for Air Pollution Measurement Systems Volume II: Ambient Air Quality Monitoring Program (Vol. II). Retrieved from http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf
US EPA. (2013b). Air Quality Index (AQI) - A Guide to Air Quality and Your Health. Retrieved from AirNow: http://www.airnow.gov/?action=aqibasics.aqi
WHO. (2005). Global Update 2005: WHO Air quality guidelinesfor particulate matter,ozone, nitrogen dioxide and sulfur dioxide. Summary of Risk Assessment

Improving Air Quality Monitoring in Asia: A Good Practice Guide
Final Report

Various studies have shown air pollution to be a serious health issue. Outdoor air pollution was classified by WHO as a human carcinogen and has been found to cause 2.1 million premature deaths annually in Asia based on estimates from the 2010 GBD. Appropriate monitoring systems have been identified as a key component in effective management of air quality. To further increase availability and scientific vigor of air quality data in Asian cities, the ADB and Clean Air Asia carried out Air Quality Interventions: Improving Air Quality Monitoring Systems in Asian Cities (Sub-Project RETA 6422) which focuses on improving air quality monitoring systems in the region and enhancing technical collaboration among Asian cities. The results of the key activities of this work have been used to prepare "A Good Practice Guidance for Improving Air Quality Monitoring in Asian Cities.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to approximately two-thirds of the world's poor: 1.6 billion people who live on less than $2 a day, with 733 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org