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Review

Air Pollution and Urban Air Quality Management in Indonesia

The trade-led industry and economic development after the Asian financial crisis a decade ago has been accelerated in Indonesia to improve the quality of life of its population. This rapid development of Indonesia was in fact heavily fueled by fossil fuels, especially oil, followed by natural gas and coal. The exploitation of fossil fuel in fueling the development resulted in significant environmental quality degradation. Air pollution is perhaps Indonesia's most severe environmental problem. Industry and transportation were the typical main sources of urban air pollutants. Moreover, Indonesia also failed to reach its original 2005 target for a complete phase-out of leaded gasoline. As a result, the level of Pb together with other pollutants such as CO, NO_x, SO_2, and total suspended particulates has exceeded or at least approached the designated ambient air quality standards. The urban air pollution will not be lesser in extent, but surely will be more severe in the future. Unfortunately, the capability of the Indonesian authorities to manage the urban air quality is still very limited and the portion of the budget allocated to the improvement of urban air quality is still remarkably low, typically 1% of total. This is why the efforts to enhance the capability to manage the urban air quality could not be handled by the environmental authorities in Indonesia's cities themselves, but outside stimulation in the form of man power, consultant and equipment assistance along with financial support has been very important.

Keywords: Air pollution; Ambient air quality standards; Fossil fuel; Urban air quality management; Urban area

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1 Introduction

The development stressed on the industry and economics in the last decade, after the financial crisis in 1997 to 1998, has successfully lifted the standard of living of Indonesia, as reflected by the improvement of its per capita gross domestic product (GDP). The per capita GDP increased from US$ 679 in 2001 to US$ 1420 in 2006, with an annual growth of 4.75% on average [1]. This average annual growth of the GDP exceeded the average growth rate of the Indonesian population as much as 1.34% in the last 6 years. Unfortunately, the growth of the GDP was not distributed equally throughout Indonesia's provinces. The extremely high per capita GDP in 2006 was recorded by provinces possessing huge natural resources such as oil, natural, gas, and copper mining.

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Abbreviations: AAQS, ambient air quality standards; **ADB**, Asian Development Bank; **AQM**, air quality management; **GDP**, gross domestic product; **PM**, particulate matter; **TSP**, total suspended particulates; **UAQi SDP**, Urban Air Quality Improvement – Sector Development Program

Indonesia's development highly depends on fossil fuels, especially oil. The annual consumption of crude oil from 1996 to 2005 was in the range of 355 to 420 million barrels. Other sources of energy were much less consumed than oil. The government data showed that the annual consumption of natural gas and hydroelectric energy from 1996 to 2005 was flat at about 104 and 20 million oil barrel equivalents, respectively. Instead of being flat, the annual consumption of two other energy sources, i.e. coal and geothermal energy, showed the trend of increase in the last years [2].

As the most consumed energy source, crude oil occupied more than half of all energy sources consumed in Indonesia. The second and third positions were recorded by natural gas and coal, while the others (geothermal and hydroelectric energy, etc.) only contributed less than 10%. The heavy dependence of Indonesian development on fossil fuel has threatened the country's environmental sustainability, due mainly to the rapid and unsustainable exploitation of these natural energy resources, and has raised a number of environmental problems, especially air pollution.

2 Air Pollution

A broad array of environmental and natural resource legislation was ratified to anticipate the unsustainable exploitation of natural

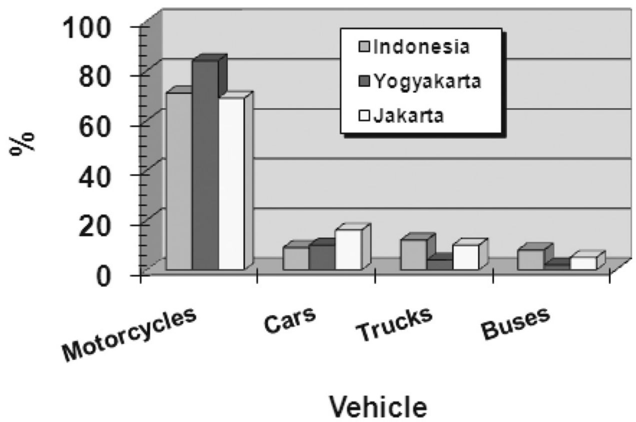

Figure 1. Composition of vehicles on national level as well as in Jakarta, and Yogyakarta in 2004.

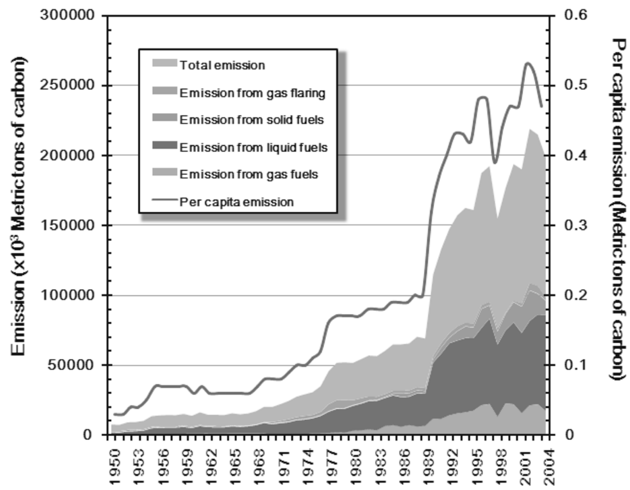

Figure 2. Emission of carbon dioxide (CO_2) by different types of fuel phase and per capita CO_2 emission in Indonesia from 1950 to 2004.

resources, but the legislation was not rigorously enforced. As a result, Indonesia recently experienced a significant environmental degradation. Air pollution is perhaps Indonesia's most severe environmental problem. It has a very serious impact on public health. For example, inflammation of the respiratory tract, which is directly linked to air quality, was the sixth leading cause of death in Indonesia, after accidents, diarrhea, cardiovascular disease, tuberculosis, and measles [3].

2.1 Sources

Motor vehicles are one of the most important sources of air pollution in every urban area in Indonesia. From 2001 to 2004, the number of vehicles in Indonesia and in the most condensed cities in Indonesia, i. e., Jakarta and Yogyakarta, grew from 21 to 37 million [4], from 7.90 to 8.05 million [5], and from almost 500 to 800 thousands [6], respectively. Many of these vehicles, approximately 71% for Indonesia, 69% for Jakarta, and 84% for Yogyakarta (see Fig. 1), were motorcycles or scooters which lack catalytic converters required for cleaner emissions. Moreover, almost none of the motor vehicles in Indonesia use unleaded gasoline, leading to unhealthily high concentrations of airborne lead (Pb).

Efforts to extend the ban on leaded gasoline throughout all of Indonesia were unsuccessful. Indonesia's effort to phase out unleaded gasoline began almost a decade ago and has received significant assistance from the U.S Environment Protection Agency (USAID). Pertamina, the state-owned oil company, failed to fulfill the Energy Ministry's Decree No.1585/1999, which mandated that unleaded gasoline must be available nationwide by January 2003. The government also failed to reach its original 2005 target for a complete phase-out of leaded fuel and has not yet announced a new target date. Insufficient facilities and funding constraints have limited Pertamina's ability to supply unleaded fuel nationwide. There is, on the other hand, resistance to authorizing private refiners to either produce or import unleaded gasoline, while Pertamina has very limited (25%) refinery capacity. While nearly all countries in the world move from using leaded gasoline to unleaded gasoline, the same condition still remains in Indonesia from the mid 1990s [3, 4]. In Indonesia, leaded gasoline is still being sold in all gasoline stations. The content of lead in the gasoline sold in Yogyakarta is typically 0.06 to 0.07 g/L [7].

The total carbon dioxide (CO_2) emission from Indonesia increased sharply, starting at the end of the 1980s (see Fig. 2) [8]. This increase was disturbed by significant decreases in 1998 due to the economic crisis beginning in 1997, but was then rapidly recovered. Liquid fuels dominated the emission of CO_2, indicating that this phase of fuel was the most consumed fuel in Indonesia. As stated above, crude oil was indeed the dominant type of energy source consumed in Indonesia. The profile of total CO_2 emission was mimicked by the per capita CO_2 emission. This indicates that the extent of the emission change of CO_2 is much more dominant than the extent of the population change, since the per capita CO_2 emission is obtained by dividing total emissions of CO_2 by the population for a particular year.

The CO_2 emission by sector in 1999 in Indonesia showed that industry-related activities contributed 55% of the total CO_2 emission, while transportation, residences, and others contributed 24, 17 and 4%, respectively [7]. As the contribution of the industrial sector was dominant and more than 50%, the profile of the CO_2 emission with its rapid increase after the economic crisis in 1997 to 1998 (see Fig. 2) may be significantly caused by the industrial sector, which consists of cement, chemical, petroleum, coal, plastics and rubber products, food industries, *etc.* Thus, the industry in Indonesia should significantly contribute to air pollution. Unfortunately, there is only limited quantitative data on their overall impact.

For Yogyakarta, the air pollution from the industrial sector mainly comes from small- and home-scale industries. The total industries in Yogyakarta city and its vicinity in 2004 were 11,908 [9]. Mostly with no facility to treat their gas exhausts, their adverse effect on the air quality may not be negligible.

Other sources of air pollution include biomass burning, fuel consumption from domestic and street vendors' cooking, solid waste burning (including municipal incinerators and open burning), forest fires, volcano activity, and others such as construction. Indoor air pollution (mainly from cooking) may contribute significantly to the adverse health effects. Although some of these activities could be significant sources of air pollution, their exact impact is largely unknown.

Transportation (vehicles) generally contributes significantly to the emissions of carbon monoxide, hydrocarbons, nitrogen oxides, and total suspended particulates (TSP), while the industry is an

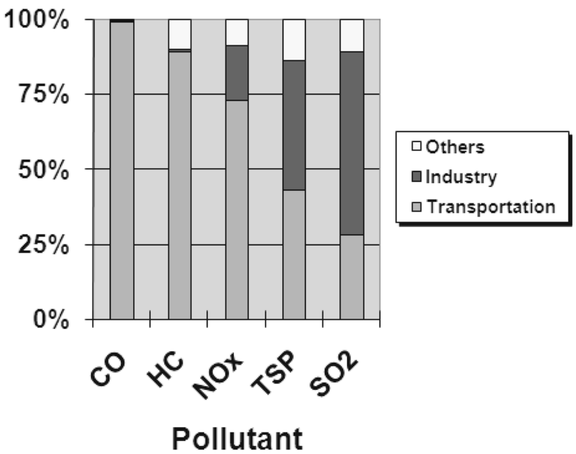

Figure 3. Contribution of transportation and industrial sectors to the emission of pollutants in Jakarta (2001).

important source of sulfur dioxide. For Jakarta, the quantitative data on the contribution of transportation and industrial sectors to the emission of pollutants in 2001 is presented in Fig. 3 [4]. Transportation contributed nearly all CO emissions. The contribution of the transportation sector to the other pollutants except SO_2 was still more dominant compared to that of the industry. Only for SO_2, the industry was the main polluter, while sectors other than transportation and industry only contributed negligible emissions of CO and approximately 10% emission of other pollutants.

Compared to Jakarta and other main cities in Indonesia, Yogyakarta possesses an important and very characteristic feature related to its closeness to the Merapi volcano. The volcano is located in the northernmost part of DIY (special region of Yogyakarta) and approximately just 15 km from Yogyakarta City. Due to its record as the most active volcano in the world, the Merapi together with the Etna in Italy were predicated by the International Natural Disaster Reduction (INDR) of the United Nations in 1993 as the Decade Volcanoes. The Merapi volcano shows its activity every day and ejects 149 tons of SO_2 per day with a rate of 3 to 4 m/s [4]. Another study estimated that the Merapi volcano has released 30 to 200 tons of SO_2 per day for centuries [10]. A relatively big eruption commonly takes place every 3 to 4 years and its fine volcanic ash frequently reaches Yogyakarta City. Therefore, the daily activity and particularly the eruptions of the Merapi volcano may considerably affect the concentrations of pollutants such as SO_2 and TSP.

2.2 Pollutants

Due to the discontinuity and generally short periods of measurement, the lack of advanced sensitive, precise and reliable methods of analysis as well as the limited coverage of measurement stations, the description of every pollutant given in the next passages is based on the available data whose accuracy, reliability, and comprehensiveness still actually need to be improved.

The existing data shows that the air quality in the big cities and industrial areas in Indonesia currently exceeds Indonesia's ambient air quality standards (AAQS) for several pollutants. Indonesia's, Yogyakarta's, and Jakarta's AAQS are summarized in Tab. 1 [11, 12]. Just for an illustration, the highest average annual measurements from four ambient air quality monitoring stations in Jakarta were estimated in 1998 as follows: NO_x 120 μg/m^3; SO_2 28 μg/m^3; fine particles less than 10 μm in diameter (PM_{10}) 81 μg/m^3; and ozone (O_3) 42 μg/m^3. NO_x and O_3 exceeded the AAQS, while SO_2 was still below the AAQS. PM_{10} was remarkably high and exceeded the AAQS of Yogyakarta (the annual AAQS of PM_{10} for Jakarta is unavailable). A

Table 1. Indonesia's, Yogyakarta's, and Jakarta's AAQS.

Pollutant	Averaging time	Standard					
		National		Yogyakarta		Jakarta	
		ppm	μg/m^3	ppm	μg/m^3	ppm	μg/m^3
SO_2	1 hour	0.34	960	0.34	960	0.34	960
	24 hours	0.14	365	0.14	365	0.10	260
	1 year	0.02	60	0.03	80	0.02	60
CO	1 hour	27.00	30 000	27.00	30 000	23.00	26 000
	8 hours	–	–	9.00	10 000	–	–
	24 hours	9.00	10 000	–	–	8.00	9 000
NO_2	1 hour	0.20	400	0.20	400	0.20	400
	24 hours	0.08	150	0.08	150	0.05	100
	1 year	0.05	100	0.05	100	0.03	60
O_3	1 hour	0.12	235	0.12	235	0.10	200
	8 hours	–	–	0.08	157	–	–
	1 year	0.026	50	0.026	50	0.015	30
HC	3 hours	0.24	160	0.24	160	0.24	160
TSP	24 hours	–	230	–	230	–	65
	1 year	–	90	–	90	–	15
PM_{10}	24 hours	–	150	–	150	–	150
	1 year	–	–	–	50	–	–
$PM_{2.5}$	24 hours	–	65	–	150	–	65
	1 year	–	15	–	50	–	15
Pb	24 hours	–	2	–	2	–	2
	3 months	–	–	–	1.5	–	–
	1 year	–	1	–	1	–	1

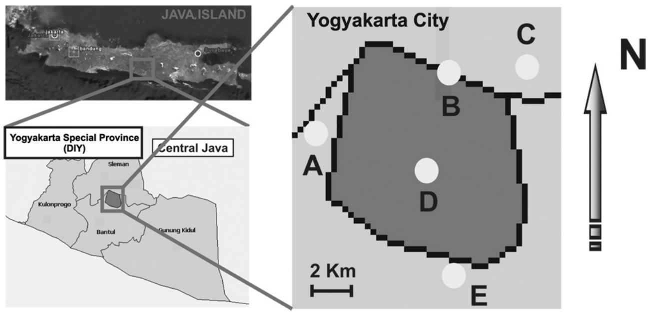

Figure 4. Sampling stations for monitoring air pollutants in Yogyakarta. Sampling locations A (Ruko Bayeman) and D (Ahmad Dahlan) are residential areas, B (Mirota Kampus) and C (Ruko Janti) are commercial areas, while sampling station E (Hotel Matahari) is a traditional market area.

dramatic increase of the average annual concentration was shown by Pb. While the average annual concentration of Pb in 1998, i.e. 0.42 μg/m^3, was still far below the AAQS, its average annual concentration in 2000 jumped to levels above the AAQS, i.e. 1.30 μg/m^3.

Taking the national AAQS as a basis, Yogyakarta's AAQS is more tolerant with regard to the hourly CO and ultrafine particles less than 2.5 μm in diameter ($PM_{2.5}$), and also to the daily $PM_{2.5}$. In the case of Jakarta's AAQS, it is tighter than the national AAQS for nearly all pollutants.

2.2.1 Particulates

Fine particulates in the air are a major health threat to Indonesians. Irritation of mucous membranes and the possible initiation of a variety of respiratory and other diseases are the major concerns associated with particulates. Finer particles, PM_{10} and especially $PM_{2.5}$, are the most harmful.

In ambient air, particulates are usually present with a number of other pollutants. Many epidemiological studies have demonstrated that particulates and SO_2 act synergistically; thus a combination of TSP and SO_2 poses high health risks [13]. Unfortunately, finer particulates are only now beginning to be monitored and most historical data refer only to TSP.

Jakarta, the most polluted city in Indonesia in terms of TSP, has a relatively high concentration of particulates compared to most other Asian cities [3]. It is estimated that 35% of the emissions of particulates are discharged from fuel combustion (including domestic cooking), 30% from transportation sources, 15% from industrial processes, 12% from other sources (including construction and dust), and 8% from solid-waste disposal (including municipal incinerators and open burning) [14]. In several smaller cities (Surabaya, Semarang, Bandung, Yogyakarta, and Cirebon), the daily concentrations of TSP from 2002 to 2004 ranged from 68.9 to 476 μg/m^3. This means that the concentrations of TSP in these cities sometimes exceeded the national AAQS (230 μg/m^3) [4].

More comprehensive monitoring of TSP was conducted in Yogyakarta. The locations of five different selected sampling stations in Yogyakarta city are shown in Fig. 4. Sampling stations A (Ruko Baye-

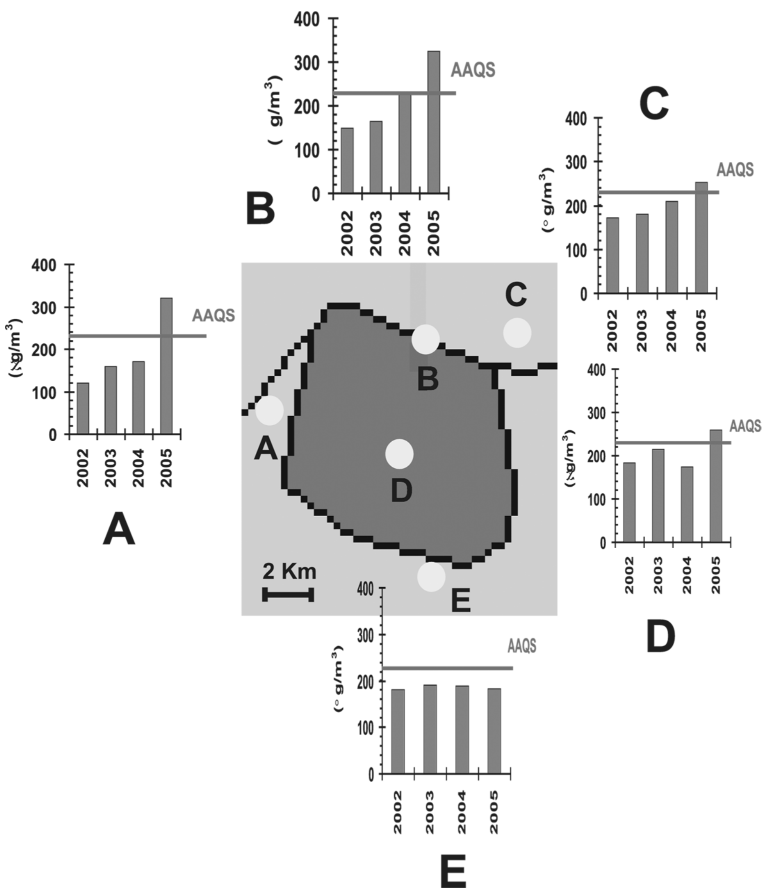

Figure 5. Daily average concentration of atmospheric TSP in five sampling stations in Yogyakarta from 2002 to 2005.

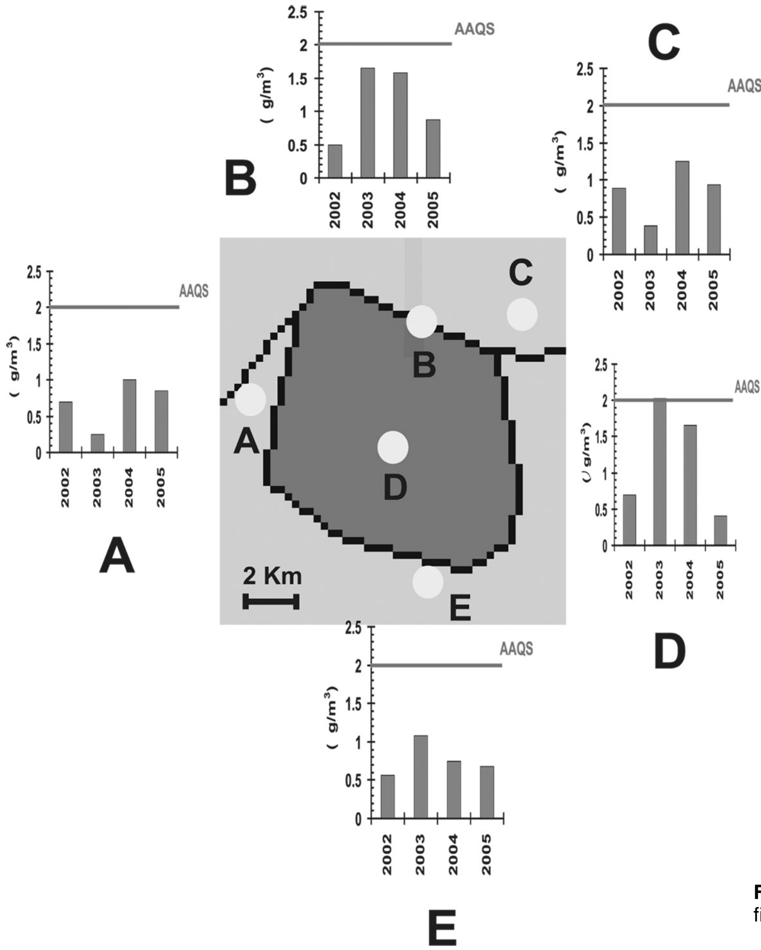

Figure 6. Daily average concentration of atmospheric lead (Pb) in five sampling stations in Yogyakarta from 2002 to 2005.

man) and D (Ahmad Dahlan) are residential areas, B (Mirota Kampus) and C (Ruko Janti) are commercial areas, while sampling station E (Hotel Matahari) is a traditional market area.

The monitoring results for these five sampling sites in Yogyakarta showed that the daily average concentration of TSP tended to increase from 2002 to 2005, and nearly all sites had average concentrations in 2005 above the daily AAQS (see Fig. 5) [6]. In addition to the number of vehicles that continuously increases, the lack of equipment for clean exhaust emission may be the main reason for the observed trend.

2.2.2 Lead

The World Bank has identified Pb emissions from gasoline as a great environmental danger to Indonesians, especially to children [3]. Exposure to lead, primarily from leaded gasoline, lead smelters and lead paint, has been demonstrated to have an impact on the nervous, renal, reproductive, hepatic, cardiovascular, and gastrointestinal systems. Children are extremely sensitive, and their IQ, cognitive development and behavior can also be significantly affected by exposure to lead.

The daily average concentrations of Pb in the atmosphere of several main cities in Jawa from 2002 to 2004 were significantly below the AAQS [4]. During this measurement period, the daily average concentration was in the range of 0.034 to 1.57 $\mu g/m^3$. Closer inspection showed that, actually, the level of Pb in 2004 was most frequently lower than that in 2003. This trend was also observed in 2005 for many sampling sites in Yogyakarta (see Fig. 6) [6]. In all sampling sites, the daily average concentration of Pb in 2004 was higher than that in 2005. The decrease of ambient Pb concentrations starting in 2004, or in 2005 in the case of Yogyakarta, may be caused by the efforts of the Indonesian government to phase out Pb from gasoline. Although the effort to change the leaded gasoline to unleaded gasoline was unsuccessful, the effort yielded a decrease of the Pb content in gasoline from 0.30 g/L in 1999 to 0.06 g/L in 2006 [4].

2.2.3 Sulfur Dioxide

SO_2 is emitted when fuels containing sulfur are combusted. It is a harsh lung irritant. The industry and power plants are the most important sources of anthropogenic SO_2 in Indonesia. When there were no big industry and power plants in Yogyakarta, the hourly average concentration of atmospheric SO_2 in the sampling stations in Yogyakarta was recorded as significantly lower than its AAQS (960 $\mu g/m^3$) [6]. In addition, atmospheric SO_2 can rapidly combine with moisture in the air to form acid rain, which affects crops, forests, buildings, and surface water quality. This high reactivity of SO_2 toward moisture in the humid atmosphere of Yogyakarta may play a significant role in scavenging SO_2 from the atmosphere, although the input of SO_2 gas from the Merapi volcano is considered significant.

2.2.4 Nitrogen Dioxide

The main sources of NO_2 pollution are motorized traffic and the industry [14]. NO_2 increases susceptibility to infections; it irritates lungs, causes edema, bronchitis, and pneumonia, and can also induce asthmatic attacks.

In Jakarta, the NO_2 concentrations increased quantitatively from 2003 to 2004 [4]. Most parts in Jakarta had average concentrations of NO_2 in 2003 significantly lower than the AAQS for Jakarta (60 μg/m^3), while in 2004 most parts of Jakarta had average concentrations of NO_2 higher than Jakarta's AAQS, but still lower than Indonesia's AAQS (100 μg/m^3).

Unlike in Jakarta, the atmospheric NO_2 in Yogyakarta generally decreased from 2002 to 2005, and was still below the AAQS (100 μg/m^3) [4]. During a 4 year measurement, the hourly average concentration range for atmospheric NO_2 in Yogyakarta was from 15 to 90 μg/m^3, while its AAQS was 400 μg/m^3.

2.2.5 Carbon Monoxide

CO is produced primarily due to the incomplete combustion of vehicular fuel. CO impairs perception and thinking and slows reflexes. It brings on angina and can cause unconsciousness and death [14].

The daily average concentrations of atmospheric CO in 2001 for various cities in Indonesia, such as Bandung, Semarang, and Pekanbaru, were significantly above Indonesia's AAQS (10 mg/m^3) [3]. In the case of Yogyakarta, the hourly average concentration at various sampling sites from 2002 to 2005 was still far below the AAQS (30 mg/m^3) [6].

2.2.6 Ozone

There are no direct emissions of O_3 into the atmosphere. O_3 is mainly formed indirectly by the action of sunlight on nitrogen dioxide. As a result of the various reactions that take place in the atmosphere, O_3 tends to build up downwind of urban centers, where most of the NO_x is emitted from vehicles. Ozone causes a range of acute effects, such as eye, nose and throat irritation, chest discomfort, cough and headache [14]. The trend of annual average concentrations of O_3 in Jakarta increased from 2001 to 2003 [4]. All the annual concentrations in 2001, 2002, and 2003 were above Jakarta's AAQS (30 μg/m^3), but only the annual concentrations in 2002 and 2003 exceeded Indonesia's AAQS (50 μg/m^3).

The atmospheric concentration of O_3 in Yogyakarta is significantly lower than that in Jakarta. Although, the hourly average concentrations were observed to increase from 2003 to 2005 [6], they were also still far below the AAQS (235 μg/m^3).

2.2.7 Acid Rain, Dissolved Nitrate and Sulfate

The acidity of rain is increasing in Indonesia, which could have a significant impact on the environment. The average pH level in rainfall for 1998 was 4.8 for ten cities in Indonesia, revealing an increase in acidity from the 1996 levels of 5.5 [3]. Although all ten cities had pH levels in rainwater lower than 5.5, the most acidic levels were found over Jakarta, followed closely by Surabaya and Bandung.

Acid rain is caused by the dissolution of NO_2 and SO_3 in the atmosphere into rainwater to form nitric (HNO_3) and sulfuric (H_2SO_4) acids, respectively. Once HNO_3 and H_2SO_4 are dissolved in water, they are ionized to release the hydronium ion (H^+) and the remaining anions of nitrate, sulfate and, to a lesser extent, bisulfate. Since the release of H^+ from HNO_3 and H_2SO_4 is always accompanied by the release of NO_3^- and SO_4^{2-}, the increasing acidity of rainwater results in increased NO_3^- and SO_4^{2-} contents in rainwater. The NO_3^- concentrations in rainwater from the years 1996 to 1998 were highest in Bandung (3.0 mg/L), followed by Jakarta (2.3 mg/L) and Surabaya (1.2 mg/L) [3].

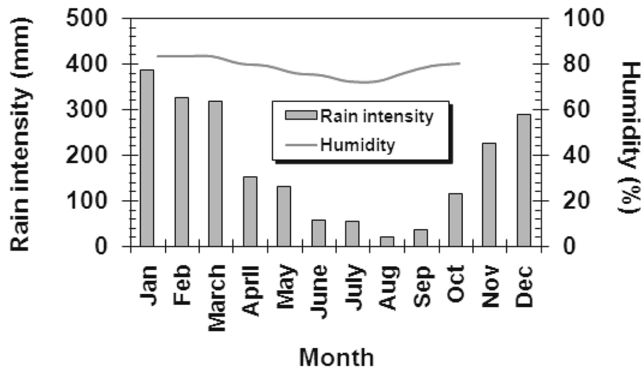

Figure 7. Monthly average rain intensity and humidity in Yogyakarta in 2005.

The average SO_4^{2-} concentrations in rainwater during the same period as given for NO_3^- were also high in Bandung (3.5 mg/L). One reason for the high level of pollution in Bandung is its location on a plateau surrounded by hills. Jakarta and Surabaya experienced similar concentrations over this time period.

Although there is still no data, Yogyakarta may experience more severe acid rain and higher concentration of dissolved SO_4^{2-}. As mentioned above, Yogyakarta is located close to the active Merapi volcano which ejects 149 tons of SO_2 per day [6]. Since SO_2 is chemically reactive to moisture, this species is rapidly dissolved as SO_4^{2-} and deposited.

Unlike in temperate zones with a relatively dry atmosphere, SO_2 and metals released by a volcano can self-maintain for a long time in the atmosphere, mixed with industrial pollution, and then be transported away over hundreds of kilometers. The high water vapor content of the atmosphere of Yogyakarta especially during the rainy season (December to April) (see Fig. 7) [9] plays a powerful role of a sink of SO_2.

The input of acidifying species like SO_2 and metals from volcanoes into the atmosphere is globally weak compared to that of industrial activity [15]. This may not be true for areas such as Yogyakarta that permanently receives local input of SO_2 from the Merapi volcano. This is why, in addition to the common air pollutant described above, Yogyakarta may represent an ideal place for a study of acid rain and its related chemical components such as dissolved SO_4^{2-} and NO_3^-.

3 Urban Air Quality Management

Indonesia still has no integrated, systematic, and strategic air quality management (AQM). The measurement of air pollutants is frequently conducted sporadically and in a short period. The measurement is mainly done with manual-type stations and still heavily depends on foreign support because the budget for the environment-related activity is very low. The budget allocated to urban air

Table 2. Benchmarking urban AQM in selected Asian cities.

Selected city	Indicator rating	Score		Management capacity[a)]
Tokyo	Air quality measurement capacity	•••••	excellent	Stage 5 (Excellent)
	Data assessment and availability	•••••	excellent	
	Emission estimates	•••••	excellent	
	Management enabling capabilities	•••••	excellent	
Beijing	Air quality measurement capacity	•••••	excellent	Stage 4 (Mature)
	Data assessment and availability	•••••	excellent	
	Emission estimates	•••••	good	
	Management enabling capabilities	•••••	good	
Jakarta	Air quality measurement capacity	•••	moderate	Stage 3 (Evolving)
	Data assessment and availability	•••	moderate	
	Emission estimates	••••	good	
	Management enabling capabilities	••••	good	
Surabaya	Air quality measurement capacity	•	minimal	Stage 2 (Basic)
	Data assessment and availability	••	limited	
	Emission estimates	•••	moderate	
	Management enabling capabilities	•••	moderate	
Yogyakarta	Air quality measurement capacity	•	minimal	Stage 2 (Basic)
	Data assessment and availability	••	limited	
	Emission estimates	•••	moderate	
	Management enabling capabilities	•••	moderate	
Karachi	Air quality measurement capacity	••	limited	Stage 1 (Minimal)
	Data assessment and availability	••	limited	
	Emission estimates	•	minimal	
	Management enabling capabilities	•	minimal	

a) Stage 5 (Excellent):
AQM is a routine activity; well established local institutional capacity; typically stable AQ levels and under WHO guidelines and NAAQS; strong emphasis on pollution prevention; AQ and emission standards are routinely enforced.
Stage 4 (Mature):
AQM is increasingly comprehensive and well structured; external, donor involvement limited only to special areas; AQ levels approaching WHO guidelines as well as NAAQS; continuous AQ monitoring; development of medium-term AQM strategies; emerging emphasis on prevention of pollution; enforcement of standards becoming standard practice.
Stage 3 (Evolving):
Systematic approach to AQM being put in place, often with still extensive foreign support; AQ monitoring increasingly through continuous monitoring; air pollution levels high but stable; more structured approach to enforcement emerging.
Stage 2 (Basic):
Initial legislation, standards and control measures; heavy dependence on foreign support; AQ levels high and still increasing; few, often manual-type stations for monitoring; often very weak AQ regulations enforcement.
Stage 1 (Minimal):
No established AQM capacity; increasing air pollution levels; no comprehensive AQ legislation and standards; limited ad-hoc AQ monitoring and pollution control.

quality improvement on the national level and in the most condensed cities in Indonesia, i.e. Jakarta and Yogyakarta, increased from 2003 to 2005, but its portion relative to the total budget was still remarkably low. The portion of budget allocated to urban air quality improvement in Yogyakarta increased from 1.5% in 2003 to 2.8% in 2005, while that in Jakarta increased from 2.2 to 2.65%. Compared to the national level, Yogyakarta and Jakarta still fortunately had a higher portion of the budget allocated to the improvement of urban air quality. On the national level, the portion of budget for urban air quality improvement has already been set to 1% of the total Indonesian budget [16]. For the Indonesian government, the priority for implementing the budget is still on sectors having direct positive effect on the society.

Huizenga et al. [17] conducted a benchmarking study of urban AQM for 23 Asian cities based on four indicators, i.e. air quality measurement capacity, data assessment and availability, emission estimates, and management enabling capabilities (see Tab. 2). These four indicators were scored in order of excellence, from the best to limited to the worst, and based on this benchmarking the management capacity of Asian cities was then ranked into five different stages. The most developed management capacity was ranked as stage 5, while the least was ranked as stage 1. This study was an international collaborative effort led by the Stockholm Environment Institute's (SEI) Centre at the University of York (UK) and the Clean Air Initiative for Asia Cities (CAI-Asia) together with the Korea Environment Institute (KEI) (Seoul) and the United Nations Environment Program (UNEP) (Nairobi). The study was funded by the Swedish International Development Cooperation Agency (SIDA), the Korean Ministry of Environment and the Asian Development Bank (ADB) [18].

As summarized in Tab. 2 for six selected cities, of the three Indonesian cities, i.e. Jakarta, Surabaya, and Yogyakarta, Jakarta had management capacity in stage 3 (Evolving), while Surabaya and Yogyakarta fell into stage 2 (Basic). For all cities benchmarked, the best management capacity, i.e. stage 5 (Excellent) was achieved by Hong Kong, Osaka, Seoul, Singapore, Tokyo and Taipei; stage 4 (Mature) was reached by Bangkok, Beijing, Busan, New Delhi and Shanghai; stage 3 (Evolving) was obtained by Ho Chi Minh, Jakarta,

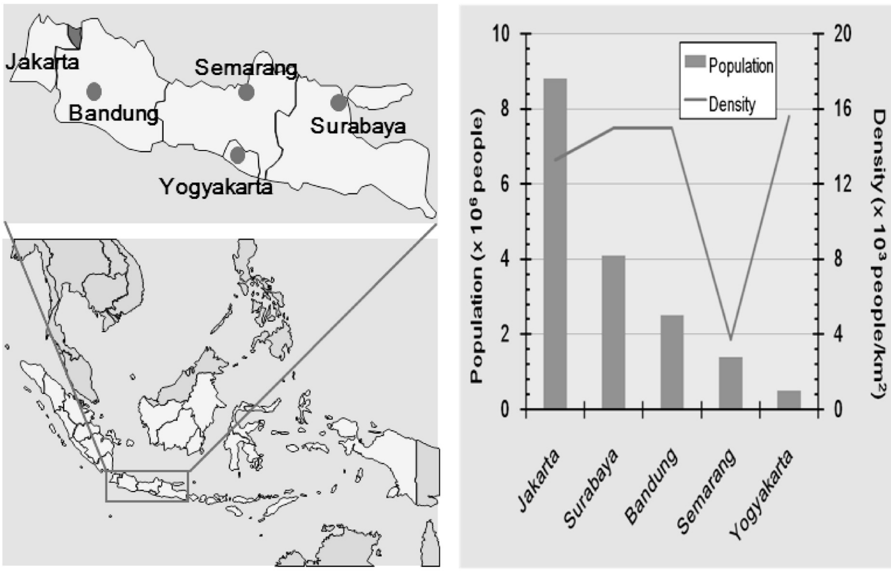

Figure 8. The five cities receiving direct technical assistance in composing strategy, action plan, and local infestation for the UAQi SD and their population densities.

Kathmandu, Kolkata, Manila and Mumbai; stage 2 (Basic) was for Dhaka, Hanoi, Surabaya and Yogyakarta; and stage 1 (Minimal) was given to Colombo and Karachi.

From the study above, it is clear that much work still needs to be done for Indonesian cities to further develop their AQM capability and to learn from cities such as Tokyo and other cities in stage 5 which are advanced in achieving better air quality. This work may include:

- Development of more accurate and precise methods of determination
- Determination of and monitoring air pollutants
- Development of more reliable inventories of air pollution emissions
- Taking a more integrative approach to determining air pollutants
- Better inspection and source identification of emissions
- Estimation and quantification of emission sources
- Taking a more strategic approach to managing air quality to include all aspects of the problem
- Harmonization of air quality standards across Indonesia
- Adopting more stringent vehicle emission standards
- Using cleaner fuels for motor vehicles, industry and power plants
- Stricter enforcement of legislation and more stringent standards for air quality

In recognition of the growing severity of air pollution and the weak capacity of Indonesia in managing urban air quality, the World Bank initiated the Urban Air Quality Management Strategy (URBAIR) in 1992 as part of its Metropolitan Environmental Improvement Program (MEIP) [4]. In 1995, the Japan International Cooperation Agency (JICA) and the Indonesian Environmental Control Agency (Bapedal) cooperated to conduct an integrated air quality management (IAQM) study that also developed an air pollutant map for Jakarta, Bogor, Tangerang and Bekasi [4].

For the first time, the Indonesian government in 1999 established a comprehensive network of ambient air quality monitoring stations in ten cities (Jakarta, Bandung, Semarang, Surabaya, Denpasar, Medan, Pekanbaru, Palangkarya, Jambi, and Pontianak) with funding from the government of Austria. The network monitoring stations, consisting of 33 fixed and 9 mobile stations, monitored the concentrations of SO_2, PM_{10}, CO, O_3, and NO_2. In addition, the network meteorological stations measured information such as wind direction and speed, humidity, solar radiation, and temperature.

Recently, with the support from ADB, the Indonesian government launched the Urban Air Quality Improvement − Sector Development Program (UAQi SDP) [4]. The first step of UAQi SDP, starting from April 2005 to September 2006, was the development of a strategy as well as an action and infestation plan on national and local levels by involving technical assistance from environmental consultants. The second step is the preparation of program implementation which is conducted during 2007, followed by implementation in the third step which will be performed in 2008.

There were ten cities in Indonesia involved in developing the national level of the strategy and action plan, but for the initial step only five cities, i. e., Jakarta, Bandung, Yogyakarta, Semarang and Surabaya (see Fig. 8), received direct technical assistance in composing their strategy, action plan, and local infestation program. Except for Semarang, the cities receiving direct technical assistance were the most condensed cities in Indonesia, with densities of more than 13,000 people/km^2. Semarang was included in the cities receiving assistance partly due to the fact that Semarang grew as a new industrial center in the middle of Jawa Island. Through the development of a city network for clean air, at least the other five cities, i. e., Palembang, Batam, Medan, Makasar, and Denpasar, will receive the benefit of the UAQi SDP.

4 Summary and Remarks for the Future

The rapid development after the financial crisis in 1997 has improved the quality of life of most Indonesians, but this improvement was not equally experienced by all people. Moreover, Indonesia's development was heavily fueled by fossil fuels, especially oil. Other sources of energy were much less consumed than oil. Together with natural gas and coal, oil traditionally contributed more than 80% of the consumed fuel for the development in Indonesia. This exploitation of fossil fuel for fueling the development resulted in significant environmental quality degradation. As reflected by the sharp increase of CO_2 emissions starting from the end of the 1980s and the rapid growth of vehicle numbers, air pollution is perhaps Indonesia's most severe environmental problem. The industry contributed slightly more than half of the total CO_2 emissions, and because most industries had no facility to treat their gas exhausts, their adverse effects on the air quality might not be negligible. Moreover, most of the vehicles (69% in Jakarta, 84% in Yogyakarta, and 71% on the national level) were motorcycles which lack the catalytic converters for cleaner exhausts, so their contribution to air pollutants, such as CO, HC, NO_x, and TSP would be severe. In the case of the industry, it is also an NO_x and TSP emitter, but its contribution as SO_2 emitter was higher.

To anticipate the air quality degradation, a broad array of environmental and natural resource legislation was ratified, but was not rigorously enforced. As an example, the Indonesian government failed to reach its original 2005 target for a complete phase-out of leaded gasoline and has not yet announced a new target date. As a result, the levels of pollutants such as CO, NO_x, SO_2 and TSP as well as Pb in the atmosphere in both a big city like Jakarta and a small but condensed city like Yogyakarta have exceeded or at least approached the designated AAQS. In addition, the acidity of rainwater in Indonesia's urban areas also increased.

Compared to main cities like Jakarta, Yogyakarta has significantly less industry and the industries in Yogyakarta are typically small- or medium-scale industries. Therefore, the role of the industry in Yogyakarta as air pollutant emitter might not be as important as its role in Jakarta. In addition to transportation and industry, input of pollutants from the nearby volcano might also be significant for Yogyakarta. The most active volcano in the world, i. e. the Merapi volcano, is just 15 km north of Yogyakarta. It has ejected 30 to 200 tons of SO_2 per day for centuries [10], but gave no appreciable effect on the atmospheric SO_2 in Yogyakarta. It was deduced that there was a possible rapid sink for that SO_2 input. High humidity might be the main reason for this rapid sink.

The urban air pollution will not be lesser in extent but will surely be more severe in the future, partly because of the urbanization. Urbanization caused the population in the cities to grow rapidly from being very low (approximately 35%) compared to the people living in rural areas in 1985 to being relatively high (50%) in 2005 [19].

Considering that cities in Indonesia (Surabaya and Yogyakarta) have only a basic capability in managing urban air quality, while Jakarta is only one stage better, i. e. evolving capability in managing urban air quality [17], it is essentially imperative to enhance soon this capability, at least for the first step regarding the incorporation or development of more accurate and precise analytical methods for air pollutants and development of more reliable inventories of air pollution emissions.

After the capability for the above aspects has been sufficiently enhanced, the second step that includes the aspects below could be implemented:

- Taking a more integrative approach to managing air pollutant data;
- Source identification of air pollutants;
- Estimation and quantification of emission sources.

Source identification of air pollutants could be attempted by using receptor models such as the chemical mass balance (CMB) model and factor analyses. In addition, an air mass backward trajectory analysis might also be coupled to CMB and factor analyses as a powerful tool to trace the origin of an air pollutant [20, 21]. Based on the collection of analytical data of pollutants in the gaseous phase and in precipitates as well as the data of source identification, the contribution of each source to the air pollution might be estimated and quantified. The accurate data on the sources of pollution together with quantitative estimates on the contribution of each source to the air pollution would in turn determine the strategy for managing the air quality.

Because the budget allocated to the improvement of urban air quality is still remarkably low and the legislation concerning environmental and natural resources was not rigorously enforced, efforts to enhance the capability in managing air quality as mentioned above might not be able to be handled by the environmental authorities in Indonesia's cities themselves. As a result, outside stimulation in the form of man power, consultant, and equipment assistance along with financial support have been very important. More recently, with the support from the ADB, the Indonesian government launched UAQi SDP which is now at the step of preparation of program implementation after finishing the first step, from April 2005 to September 2006, of developing a strategy as well as an action and infestation plan on national and local levels, by involving technical assistance from environmental consultants. The program will soon enter the implementation step in 2008.

References

[1] *Selected Indicators Social-Economics of Indonesia*, Directorate of Statistical Dissemination, Jakarta **2006**.

[2] *Indonesia Energy Data, Statistics and Analysis – Oil, Gas, Electricity, Coal*, Jakarta **2007**.

[3] T. E. Walton, *Indonesia Environment Monitor*, World Bank **2003**.

[4] National Air Quality Map, **2006**, http://udarakota.bappenas.go.id, accessed in May 5, 2007.

[5] Jakarta LSAP Document, **2006**, http://udarakota.bappenas.go.id, accessed in May 5, 2007.

[6] Yogyakarta LSAP Document, **2006**, http://udarakota.bappenas.go.id, accessed in May 5, 2007.

[7] Climate and Atmosphere – Indonesia, **2003**, http://earthtrends.wri.org, accessed in September 22, 2007.

[8] G. Marland, T. Boden, R. J. Andres, National CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751 – 2004, http://cdiac.ornl.gov/ ftp/trends/emissions/ido.dat, accessed in November 14, 2007.

[9] Yogyakarta City Agglomeration Map, **2006**, http://udarakota.bappenas.go.id, accessed in May 5, 2007.

[10] R. G. S. Orstom, An Ecosystem under Acid Rain at Merapi Volcano Central Java, Indonesia, *5th International Congress on Ecology*, Yokohama **1990**.

[11] Indonesian Government Legislation No. 41/1999, National Ambient Air Quality Standard.

[12] Decree of Governor of Yogyakarta Special Region No.176/2003, Ambient Air Quality Standard for Yogyakarta Special Region.

[13] M. Kleeman, *Energy Use and Air Pollution in Indonesia*, Ashgate Publishing Limited, **1994**.

[14] B. Ostro, *Estimating the Health Effects of Air Pollution: A Method with an Application to Jakarta*, World Bank **1994**.

[15] H. Rhode, L. Granat, An Evaluation of Sulphate in European Precipitations 1955 – 1982, *Atmos. Environ.* **1984**, *18*, 2627.

[16] President Legislation No. 7/2005, Master Plan for Midterm Development in Indonesia.

[17] C. Huizenga, M. Ajero, H. Fabian, G. Haq, D. Schwela, Benchmarking Urban Air Quality Management in Asian Cities, *13th World Clean Air and Environmental Protection Congress and Exhibition*, 22–27 August 2004, London, UK **2004**.

[18] Study Reveals Clean Air Challenge for Major Asian Cities, **2006**, www.sciencedaily.com/releases/2006/12/061213104121.htm, accessed in May 7, **2007**.

[19] A. Prabowo, Urban Air Quality Improvement (UAQi) Program Development, *Better Air Quality Conference*, Yogyakarta **2006**.

[20] T. Okuda, J. Kato, J. Mori, M. Tenmoku, Y. Suda, S. Tanaka, K. K. He, Y. Ma, F. Yang, X. Yu, F. Duan, Y. Lei, Daily Concentrations of Trace Metals in Aerosol in Beijing, China, Determined by Using Inductively Coupled Plasma Mass Spectrometry Equipped with Laser Ablation Analysis and Source Identification of Aerosols, *Sci. Total Environ.* **2004**, *330*, 145.

[21] T. Okuda, T. Iwase, H. Ueda, Y. Suda, S. Tanaka, Y. Dokiya, K. Fushimi, M. Hosoe, The Impact of Volcanic Gases from Miyake Island on the Chemical Constituents in Precipitation in the Tokyo Metropolitan Area, *Sci. Total Environ.* **2005**, *341*, 185.

[22] S. Syahril, A. Syafruddin, B. T. Budiman, B. P. Resosudarmo et al., Indonesian Multi-Sector Action Plan Group on Vehicle Emission Reduction, Integrated Vehicle Emission Reduction Strategy for Greater Jakarta, *RETA 5937*, Asian Development Bank, **2002**.

