J. KOSAE Vol. 18, No. E 1 (2002) pp. 21~28
Journal of Korean Society for Atmospheric Environment

Technical Information

A Commentary on Air Pollution Monitoring Programs in Korea

Young Sung Ghim*, Jin Young Kim, Shang-Gyoo Shim and Kil-Choo Moon
Global Environment Research Center, Korea Institute of Science and Technology, 39-1 Hawolgok-dong, Songbuk-ku, Seoul, 136-791, Korea

(Received 1 November 2001; accepted 25 March 2002)

Abstract

Air quality issues in Korea rapidly changed at the beginning of the 1990s from primary to secondary pollutants starting in Seoul, the capital of Korea. The present frame of national air pollution monitoring networks was established between the end of the 1980s and the beginning of the 1990s. Background monitoring was initiated in the middle of the 1990s in response to increasing public concern about the long-range transport of air pollutants. Apart from the national monitoring, both routine and intensive measurements of fine particles have been made for research purposes since the middle of the 1990s at several background sites. However, air pollution monitoring in urban areas for other purposes was relatively scarce as national monitoring has been concentrated in these areas. Although ozone pollution has become a significant issue in major metropolitan areas every summer, only a little information on ozone precursors is available. During the past few years, the number of national monitoring stations has greatly increased. The government has a plan to gradually expand monitoring items as well as stations. It is anticipated that highly detailed information on both photochemical reactants and products will be available within the next several years. More emphasis will be placed on toxic substances based on risk assessment in monitoring for both research and policy making.

Key words : Air quality issues, Monitoring network, Long range transport, Fine particles, Ozone pollution, Toxic substance

1. CHANGES IN AIR QUALITY ISSUES IN KOREA

The air pollution monitoring program in Korea started at the end of the 1970s (KAPRA, 1990). In 1980, the Korea Environmental Administration (now the Ministry of Environment) was created. The concept of air quality management rather than simple pollution control at the stack was introduced at that time with the establishment of national ambient air quality standards. Until the beginning of the 1990s, the major air quality problems in Korea were high concentrations of sulfur dioxide (SO_2) and total suspended particulates (TSP) (WHO/UNEP, 1994). However, with great economic expansion through the 1980s, the Korean government was able to urge a switchover to clean fuel, and as a result concentrations of both pollutants have substantially decreased.

Table 1 shows the number of exceedances of selected short-term standards for criteria pollutants in Seoul at the beginning of the 1990s. The number of hours

* Corresponding author.
Tel : +82-(0)2-958-5817, E-mail : ysghim@kist.re.kr.

Table 1. Number of exceedances of selected short-term standards for five criteria pollutants at 20 monitoring stations in Seoul (Ghim, 1997).

Pollutant	Standard[a]	1991	1992	1993
SO_2	1-h average 250 ppb[b]	936	178	0
TSP	24-h average 300 μg/m³	124	62	38
CO	8-h average 9 ppm[c]	87	30	1
NO_2	24-h average 80 ppb[b]	43	15	40
O_3	1-h average 100 ppb	157	222	63

[a] See Table 2 for the current standards.
[b] Enforced from December 31, 1993 [c] Enforced from January 1, 1995.

exceeding the air quality standard of SO_2 was 936 in 1991; however, it completely disappeared in 1993. Similar changes are found in TSP and carbon monoxide (CO) exceedances. Particularly, the decrease in the CO exceedances is distinct in spite of the rapidly increasing number of vehicles in the same period. This is attributable to the use of three-way catalytic converters which have been installed in domestically produced automobiles since the end of the 1980s. Nevertheless, the numbers for nitrogen dioxide (NO_2) and ozone (O_3) did not decrease. The changes shown in Table 1 occurred very rapidly starting in Seoul throughout the country by the middle of the 1990s.

Figure 1 shows the status of ozone pollution in Seoul in comparison with that in major US cities. The level of ozone concentrations in Seoul is close to that in metropolitan areas in the U.S. notorious for serious ozone pollution. It is presumed that high ozone occurrences are frequent due to volatile organic compounds (VOC) and nitrogen oxides (NOx) emitted from vehicles. If this is true, it could be interpreted as meaning that the growth of emissions due to increasing number of vehicles including diesel vehicles offsets and surpasses the reduction of emissions from gasoline automobiles by the use of three-way catalytic converters.

Visibility impairment became a stubborn problem in Seoul and major metropolitan areas through the 1980s and the 1990s. As shown in Figure 2, visibility on winter mornings is generally the worst in Seoul, but has steadily improved. However, most people in Seoul do not notice this improvement. It is surmised that this

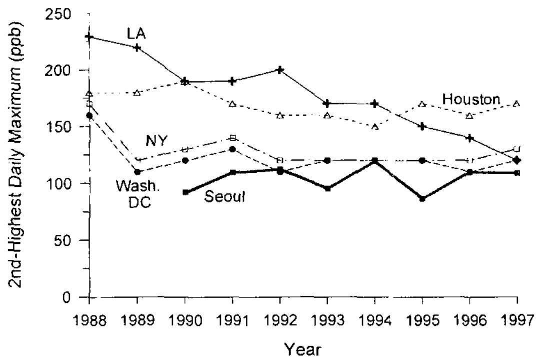

Fig. 1. Trend in annual second-highest daily maximum ozone concentration in Seoul compared with different metropolitan areas in the U.S. notorious for serious ozone pollution (Ghim, 2000).

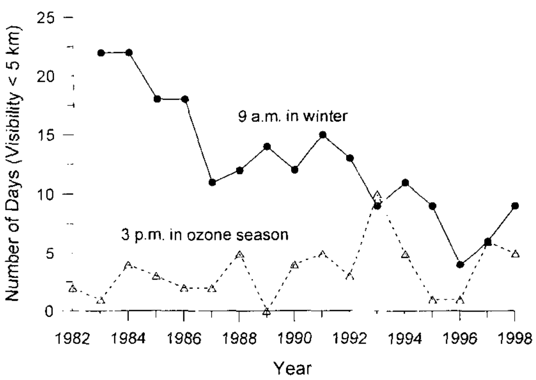

Fig. 2. Comparison of the number of days on which the visibility was less than 5 km at 9 am in winter (Dec.-Feb.) and at 3 pm in the ozone season (May-Sep.) in Seoul. Precipitating days were excluded.

perception could be related to the gray color of smog associated with relatively high concentrations of black carbon of 5 to 10 μg/m³ (Kim *et al.*, 1999). An increasing trend in the number of days in the ozone season on which the visibility in the afternoon is less than that in the morning is also noted. This trend is not distinct in most cases; however, it is thought that this could be an indication in some places of photochemical smog.

Attention to the long-range transport of air pollutants has been paid principally in association with the

Table 2. Revision of ambient air quality standards on December 31, 2000.

Pollutant	Former standard[a]	Revised standard[b,c]	Measurement method[c]
SO_2	Annual average 0.03 ppm 24-hour average 0.14 ppm 1-hour average 0.25 ppm	Annual average 0.02 ppm 24-hour average 0.05 ppm 1-hour average 0.15 ppm	Pulsed u.v. fluorescence method
CO	8-hour average 9 ppm 1-hour average 25 ppm	(Same as before)	Non-dispersive infrared method
NO_2	Annual average 0.05 ppm 24-hour average 0.08 ppm 1-hour average 0.15 ppm	(Same as before)	Chemiluminescent method
TSP	Annual average 150 μg/m³ 24-hour average 300 μg/m³	(Left out)	β-ray absorption method, high-volume air sampler method
PM_{10}[d]	Annual average 80 μg/m³ 24-hour average 150 μg/m³	Annual average 70 μg/m³ 24-hour average 150 μg/m³	β-ray absorption method
O_3	8-hour average 0.06 ppm 1-hour average 0.1 ppm	(Same as before)	U.v. photometric method
Lead	3-month average 1.5 μg/m³	Annual average 0.5 μg/m³	Atomic absorption spectrophotometry

[a] 24-, 8- and one-hour standards are not to be exceeded more than three times per year.
[b] One-hour standard is not to be exceeded by the 99.9th percentile; 8-hour and 24-hour standards are not to be exceeded by the 99th percentile.
[c] From Attached Table 1 in the Enforcement Ordinance of the Environmental Conservation Fundamental Law.
[d] Particulate matter with an aerodynamic diameter less than or equal to 10 m.

yellow sand phenomenon in spring. However, as the concentrations of primary pollutants decreased and as the public concern about air quality grew during the 1990s, acid rain also became an issue related to the long-range transport.

Discussion of fine particle problems such as PM_{10} and/or $PM_{2.5}$ is still limited to scientific society although the air quality standard for PM_{10} was newly added in 1995 and that for TSP was excluded from 2001 (Table 2). The situation was similar to that with ozone in the middle of the 1990s. However, after the ozone warning system was introduced in Seoul in July 1995 and because ozone warnings that indicate the ozone concentration exceeding 120 ppb are frequent in Seoul and other metropolitan areas, ozone pollution has become a significant issue every summer.

2. NATIONAL AMBIENT AIR MONITORING

Table 3 shows national air pollution monitoring networks in Korea taken from KME and NIER (2001). Except stations for local air and acidic deposition monitoring, most of the stations in Table 3 for other purposes started their operation after the middle of the 1990s. Even in the case of stations for local air and acidic deposition monitoring, the present frame was set between the end of the 1980s and the beginning of the 1990s, and the number of stations has greatly increased during the past few years. As in many other countries, nearly all stations are installed in urban areas except several stations for monitoring background and global concentrations (Demerjian, 2000). The monitoring stations in Table 3 are operated either by the Korea Ministry of Environment or by local government. However, visibility and global environment are also monitored by the Meteorological Administration; for example, visibility is monitored at surface weather stations distributed throughout the country (see Fig. 4).

Note that the national air pollution monitoring networks are basically for managing air quality in accordance with air quality standards. Most stations for air quality monitoring measure just criteria pollutants. For example, only NO_2 concentrations are available from

Table 3. National air pollution monitoring networks in Korea (as of December 2001; KME and NIER, 2001).

Purpose	Measurement item[a]	Number of stations		
		Total	KME[b]	Local government[b]
Local air monitoring	SO_2, NOx, O_3, CO, PM_{10}, WS, WD, Temp, RH	161	63	98
Roadside monitoring	SO_2, NOx, O_3, CO, PM_{10}, WS, WD, Temp	16	5	11
Acidic deposition monitoring	pH, precipitation	70	34	36
	pH, precipitation, EC, ion concentrations	27	27	–
National background monitoring	SO_2, NOx, O_3, CO, PM_{10}, WS, WD, Temp	5	5	–
Local background monitoring	SO_2, NOx, O_3, CO, PM_{10}, WS, WD, Temp	6	6	–
Heavy metal monitoring	Pb, Cd, Cr, Cu, Mn, Fe, Ni	40	18	22
Visibility monitoring	Visibility	2	–	2
Global monitoring	CFCs	1	1	–

[a] WS, wind speed; WD, wind direction; Temp, temperature; RH, relative humidity; EC, electric conductivity.
[b] Agency in charge of operation. KME denotes the Korea Ministry of Environment.

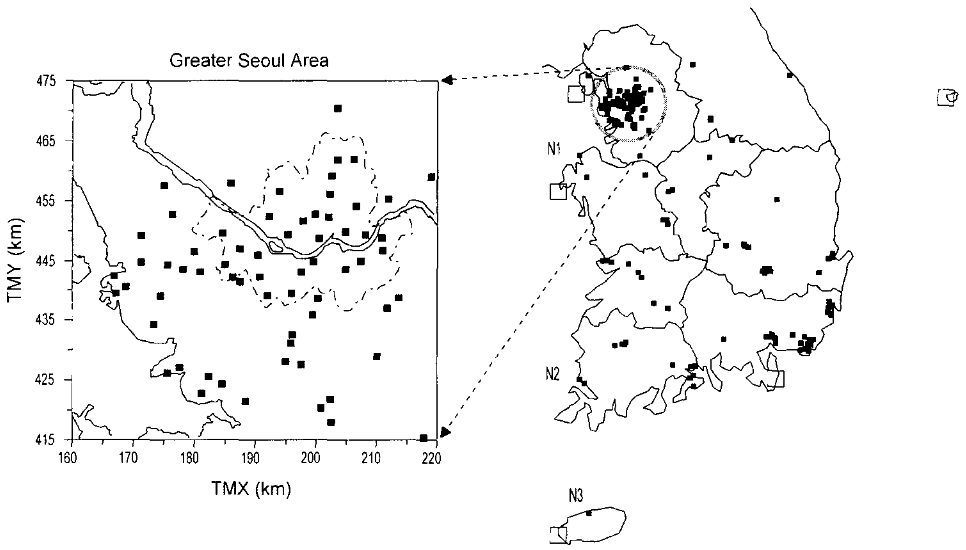

Fig. 3. Distribution of national air pollution monitoring stations in Korea and the greater Seoul area. Solid rectangles denote local air monitoring stations, and open rectangles denote national background monitoring stations. N1 to N3 denote three stations that started their operation in 1995.

monitoring stations because NO_2 is a criteria pollutant, although both NO and NO_2 are measured and furthermore the chemiluminescence technique is more reliable for NO (USEPA, 1996). Also, only PM_{10} is now available from monitoring stations since TSP was excluded from air quality standards from 2001 (Table 2). However, as can be seen in acidic deposition monitoring that measures ion concentrations as well, the government plans to gradually expand both monitoring stations and items (KME, 1998). Monitoring of VOC species similar to the PAMS (Photochemical Assessment Monitoring Stations) program in the US (USEPA, 1996) is in preparation as part of these plans.

Figure 3 shows the distribution of stations for local air monitoring (KME and NIER, 2000). As of December 2001, there were 161 stations for local air moni-

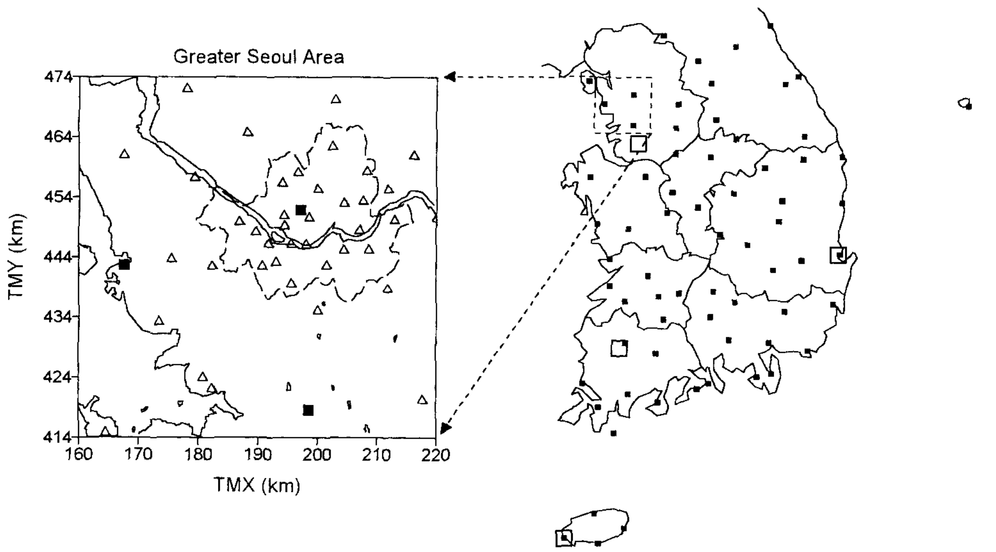

Fig. 4. Distribution of weather stations in Korea and the greater Seoul area. Solid rectangles denote surface weather stations, open rectangles denote upper air stations, and open triangles denote automatic weather stations.

toring nationwide (Table 3) and 67 stations in the GSA (the greater Seoul area; Seoul proper and its satellite cities). However, pollutant concentrations were consistently measured at about 99 stations nationwide and 38 stations in the GSA during the 1990s. It is interesting to note that three stations (N1 to N3) were newly installed on the west coast and in Cheju Island for local air monitoring in 1995 apart from national background stations. These stations are also located in urban areas but are distant from major metropolitan areas and situated in a strategic location to monitor the incoming air pollution from China. In fact, since these stations begun operating, the annual average concentrations of ozone at these stations have been the highest among all local air monitoring stations (Ghim, 2000).

In contrast to air pollution monitoring stations, surface weather stations operated by the Korea Meteorological Administration are evenly distributed as shown in Figure 4. As of 1998, there were 73 surface weather stations, but only about 68 of them were consistently in operation during the 1990s. Since Korea is mostly a mountainous area with complicated shorelines, wind fields usually vary in a very complex manner both spatially and temporally. Detailed wind fields are necessary in order to get a better result from air quality modeling. Fortunately, after some data validation procedures, it was confirmed from the end of the 1990s that observations from automatic weather stations could be used in constructing the wind field (Kim *et al.*, 2000). Figure 4 shows the distribution of automatic weather stations that is much denser than that of surface weather stations (37 stations compared with 3 surface weather stations) in the greater Seoul area.

3. MONITORING FOR RESEARCH PURPOSES

At the beginning of the 1990s, two research programs were initiated: one was for studying acid rain and the other was for studying smog in Seoul. The former has been implemented for ten years and has become a basis for studies of long-range transport. Emphasis was placed on pollution monitoring in rural and background areas, and analyses of ion concentrations became common thereafter (Lee *et al.*, 2000).

The latter program was carried out for three years. Mass and ion concentrations of fine particles as well as concentrations of carbonaceous species were first measured (Baik *et al.*, 1996). Since the beginning of the 1990s, several research teams have analyzed fine particles in urban areas in order to investigate physical /chemical properties and to identify sources (Kim, K.-S. *et al.*, 2001; Lee and Kang, 2001; Kang *et al.*, 1999). These studies were undertaken mainly because of potential health risks but also because of their influence on visibility impairment.

However, major research-purpose air pollution monitoring has been performed for studying long-range transport and regional scale variations of air pollutants since general information on air quality in major urban areas is provided by the national air pollution monitoring. In the middle of the 1990s, a research project focusing on fine particles for studying long-range transport was initiated. The national background monitoring in Table 3 has been undertaken in connection with this project. However, mass and ion concentrations of $PM_{2.5}$ are routinely measured every 6th day at these sites, which include Kosan in Cheju Island, a supersite of ACE-Asia (Asian Pacific Regional Aerosol Characterization Experiment; NOAA, 2001). During the intensive measurement periods elemental and organic carbon concentrations of $PM_{2.5}$ and gaseous HCl, HNO_3 and NH_3 concentrations are also measured (Lee *et al.*, 2001). During these measurement periods aircraft measurements have been made (Kim, B.-G. *et al.*, 2001) and since last year shipboard measurements using passenger ships along the west coast have also been made.

For the past three years the monitoring of air pollutants over the Yellow Sea for determining their input to the sea has been performed. Shipboard measurements using passenger ships crossing the Yellow Sea from Inchon to Qingdao have been made. A new ground station to the west of Kanghwa Island where the national background monitoring station is located was prepared in Tokchok Island. Figure 5 shows air pollutant sampling locations over the Yellow Sea during the past three to four years. Except shipboard measurements from Inchon to Qingdao and the ground-based monitoring at Tokchok Island, air pollutant sampling in Figure 5 has been carried out as part of the aforementioned research project for studying the long-range transport.

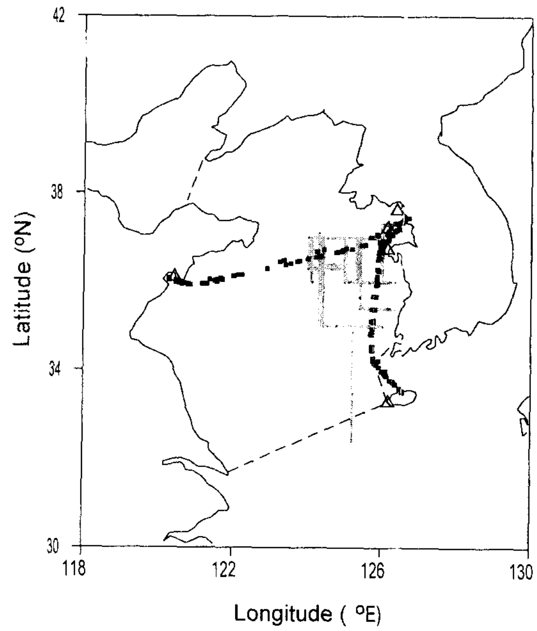

Fig. 5. Air pollutant sampling locations over the Yellow Sea (Kim, J.Y. *et al.*, 2001). Dashed lines are the northern and southern boundaries of the Yellow Sea. Open triangles denote the ground-based sampling sites: from the northwest, Qingdao, Kanghwa, Tokchok, Taean, and Kosan, clockwise. Solid rectangles show the route of shipboard measurements connecting Inchon (east of Kanghwa) and Qingdao and connecting Inchon and Cheju (northeast of Kosan). Gray lines show aircraft flight paths.

As for ozone pollution, ozone concentrations from the national monitoring stations are basically the only available information without NO concentrations. Measurements of VOC species have been made since the middle of the 1990s, but are too few to be characterized from the standpoint of photochemical reactivity (Na and Kim, 2001). Several research teams individually measured VOC species limited to those hazardous to health (Lee *et al.*, 1997). For three years in the latter half of the 1990s, photochemical products such as H_2O_2, HNO_3 and peroxyacetyl nitrate (PAN) were measured in Seoul. In the summer of 2001, measurements of NO_y (total reactive nitrogen) and carbonyl compounds were also attempted as part of an ozone field study in the greater Seoul area.

4. PERSPECTIVES

It is anticipated that much more detailed information on both photochemical reactants and products will become available within the next several years. This is because there is a consensus that current information is inadequate to be used for developing any strategies against ozone pollution. A revisit to the problem of fine particles in urban areas from the standpoint of photochemistry may also be anticipated. Determination of the effects of long-range transport of air pollutants will be an important subject. However, more emphasis will be placed on toxic substances such as persistent organic pollutants and heavy metals. In air quality management, an integrated approach on the basis of risk assessment has also been proposed.

ACKNOWLEDGMENTS

This work was supported in part by the Korea Ministry of Science and Technology under Grant 2000-N-NL-01-C-184 and in part by the Korea Institute of Science and Technology.

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