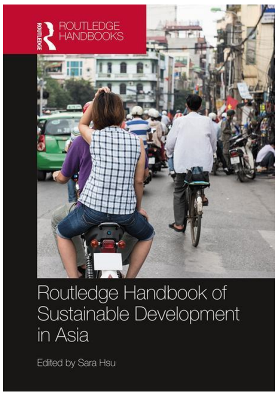

Routledge Handbook of Sustainable Development in Asia

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Air pollution and its threat to public health in Asia

Lee Liu

Introduction

Sustainable development is development that meets the needs of the present without sacrificing the ability of future generations to meet their own needs (World Commission on Environment and Development 1987). It has been illustrated as having three overlapping dimensions: the simultaneous pursuit of economic prosperity, environmental quality, and social equity, also known as the "three pillars" of sustainability (United Nations General Assembly 2005; Adams 2006; Liu 2009). Recent holistic and inclusive thinking of sustainability emphasizes overlapping dimensions and the interaction among them (Liu 2009). The question of how to achieve sustainability in Asia has long been contested, as different schools of thought exist in the interpretation of the relationship between economic development and environmental conditions. On the one hand, it is argued that the "grow (pollute) first, clean up later" path is unavoidable in some developing countries (Azadi et al. 2011). Some fast-growing Asian economies have followed that path, such as Japan, South Korea, Taiwan, and China (Rock 2002; Rock and Angel 2007). The theoretical support of the "grow first" path is provided by the environmental Kuznets curve (EKC). The EKC suggests that environmental quality first decreases and then improves with economic growth. The implication of the EKC is that economic growth is the key to achieve both economic and environmental goals (Beckerman 1992; Panayotou 1993; Ekins 2000; Weber and Allen 2010).

On the other hand, the "grow first, clean up later" approach has been long criticized and the applicability of the EKC disputed (Liu 2008, 2012, 2013a). EKC studies do not support the existence of a simple, predictable relationship between pollution and per capita income because multiple factors are involved (Stern 2004; Dasgupta et al. 2006). Harbaugh et al. (2002) conclude that there is little empirical support for an EKC relationship between important air pollutants and national income. However, governments in many Asian countries tend to promote rapid economic growth at the cost of the environment and social equity. The result is worsening environmental pollution and degradation in these countries.

Among the many environmental challenges, air pollution is a severe threat to environmental, social, and economic sustainability in Asia. Air pollution is a major cause of climate change that contributes to rising sea levels and intensification of extreme weather. Consequently, many Asian countries are losing their precious land due to desertification and rising sea levels. The loss of biodiversity has been disastrous to wildlife and ecosystems. It is the less developed countries or poorer parts of a country that are often affected the most by climate change. This causes worsening environmental injustice. Furthermore, environmental hazards threaten public health in both more and less developed countries. The World Health Organization (WHO 2014a, 2014b) estimated that indoor and outdoor air pollution exposure killed about 7 million people (one eighth of total deaths globally) in 2012. Of the 7 million deaths, 5.9 million were in the WHO's Southeast Asia and Western Pacific Regions. Lelieveld et al. (2015) estimated that outdoor air pollution (mainly PM2.5) was responsible for 3.3 million premature deaths globally, concentrated in Asia. PM2.5 refers to particulate matter (PM) 2.5 micrometers in diameter or smaller. PM2.5 can lodge deep into human lung and blood tissue. They may cause stroke, lung cancer, and even death, particularly among children and the elderly (WHO 2014c). Access to clean air is a basic human need and a human right, and comprises an important part of sustainability.

In recent years, there have been an increasing number of global and country-specific studies on air pollution and its impact on sustainability. However, Asia-specific studies are lacking. Such studies can potentially contribute to the understanding of global air pollution and sustainability. As the world's most populated region with diverse environmental, social, and economic processes, Asia is vitally important to global development and sustainability. This study will first provide an overview of air pollution in Asian countries, and its current situation with historical and regional comparison. It will provide an overview and comparison of all major countries in Asia. Variations within a country will be examined using China as a case study. The study will also explore how air pollution threatens sustainability in Asia in terms of its impact on human health. Furthermore, it will use the Asian experience to challenge the traditional approach to development such as the "grow first, clean up later" approach and the EKC, in order to promote sustainable policies.

Data and methods

Criteria for inclusion of countries/regions

This study intends to include all countries/regions in East, South, and Southeast Asia. However, some entities such as Macao, Fuji, and Brunei are small in size, and possess a unique economic structure, or incomplete data. These entities were excluded to enhance comparability among the countries/regions. Quantitative data were mainly from the WHO (2016a, 2016b, 2016c) and Yale University's Environmental Performance Index (EPI) Report (Yale University 2016a, 2016b, 2016c, 2016d, 2016e). We also note that the WHO and Yale's EPI Regions are a little different from the common geographic divisions. The Asian countries/regions included in this study belong to two different WHO and EPI Regions. The WHO classified Asia into a South-East Asia Region and a Western Pacific Region. The EPI categorizes Asian into an East Asia and Pacific Region and a South Asia Region, according to which EPI regional peer comparisons are conducted. In particular, this study excludes some Pacific countries such as Australia, New Zealand and some island countries in the western Pacific, which are in the EPI Regional comparison.

Data quality

The WHO data were based on reports by governments to the United Nations. In this case, the quality is variable because different countries/regions may use different data collection methods and guidelines. Air quality data from monitoring stations are regarded as accurate in the case of China (Rohde and Muller 2015). However, the placement of monitoring stations may be subject to various political considerations. The data quality is affected by the number of PM10 and PM2.5 stations and whether the data were measured or converted. The location of the stations in the cities matters. Some cities may place them near areas with the worst possible pollution so people will be alerted when pollution is at high levels. Chinese city officials tend to place them away from the most polluted spots because they want to use typical or representative spots for the city, or they may place some in highly polluted areas and others in less polluted areas so that the averages for the city may look "representative." This practice usually results in underestimated city averages.

Furthermore, the WHO city data on Indonesia and Sri Lanka were based on only a single station, while the number of stations for Nepal was unavailable (WHO 2016a). For Indonesia, data based on one station in the city of Bandung may not be representative of such a large country. Hong Kong uses 15 and Singapore uses 22 monitoring stations to directly measure both PM10 and PM2.5. Most cities in Bangladesh and Pakistan measure both PM10 and PM2.5 through monitoring stations. For other countries, one set of data is directly measured and the other is converted using the directly measured data. In India, Malaysia, South Korea, and Thailand, it is usually the case that PM10 is directly measured and PM2.5 is converted from PM10 measurements, In Japan and Taiwan, PM2.5 is directly measured while PM10 is converted from PM2.5 data. In China, PM2.5 is directly measured in all cities, while PM10 is directly measured in some and converted from PM2.5 measurements in other cities. Despite these variations and limitations, the data obtained were the best available for this study. Both the WHO and Yale University follow their own data collection standards and criteria and employ different methods to enhance data accuracy, completeness, and comparability across countries/regions in the published datasets.

Terminology

This study will focus on air pollution in terms of particulate matter (PM). PM is a complex mixture of extremely small particles and liquid droplets. Such a mixture may be made up of acids, organic chemicals, metals, soil, and dust. In addition to PM2.5 just discussed, another category is PM10, referring to particles larger than 2.5 micrometers and smaller than 10 micrometers in diameter. Such particles can pass through the throat and nose and enter the lungs. Thus they can cause heart and lung diseases.

PM2.5 guidelines (targets)

World organizations and countries have set different guidelines (targets) for small particulate pollution (Table 3.1). The guidelines by the WHO are the strictest. The WHO (2006) argues that small particulate pollution has health impacts even at very low concentrations – indeed no threshold has been identified below in which no damage to health is observed. Therefore, the WHO 2005 guideline limits aimed to achieve the lowest concentrations of PM possible. Few Asian countries/regions have set up these guidelines for annual averages and daily (24 hours) averages. Those published guidelines are compared to the WHO, USA, and European Union standards. Singapore, Japan, and Taiwan are quite compatible with such standards while other countries, such as China and India, have lower standards. Those Asian countries not listed in Table 3.1 do not yet have any official standards available, which are very important in fighting air pollution.

Current air pollution in Asian cities

The WHO (2016a, 2016b) just updated its urban air quality database, primarily based on government reporting. Annual mean concentrations of particulate matter (PM10 and/or PM2.5)

Table 3.1 Guidelines (targets) in Asian countries/regions for PM2.5 annual average and daily (24 hours) average (μg/m^3) as compared to the WHO, USA, and European Union standards

	Annual mean	*Daily average*
WHO	10	25
USA	12	35
European Union	25	na
Singapore	12	37.5
Japan	15	35
Taiwan	15	35
South Korea	25	50
Thailand	25	50
China	35	75
India	40	60

Sources: WHO: WHO (2006); USA: USEPA (2012); European Union: European Commission (2016); Singapore: National Environment Agency of Singapore (2016); Japan: Transport Policy Net (2016a); Taiwan: Environmental Protection Administration, ROC (2015); South Korea: Air Korea (2016); Thailand: Transport Policy Net (2016b); China: MEP (2012); India: IES (2016).

were based on daily measurements, or data which could be aggregated into annual means (WHO 2016a). The database includes PM10 and PM2.5 levels in selective monitored cities in 15 Asian countries or regions (Table 3.2). The number of cities in each country or region varied from just one to 194. The data indicate that South Asian countries, Pakistan, Bangladesh, and India, tend to have very high PM10 and PM2.5 levels. The highest annual average PM10 was 540 ug/m^3 in Peshawar, Pakistan. The highest annual average PM2.5 was 176 ug/m^3, which is 17.6 times the WHO limit, in Gwalior, India. China is fourth in terms of urban PM2.5 pollution with an annual average at 55 ug/m^3, 5.5 times the WHO limit. Urban Japan is the least polluted with an annual average PM2.5 at 15 ug/m^3 and PM10 at 28 ug/m^3. Malaysia, Singapore, Taiwan, South Korea, and Thailand are also among the least polluted. The means of PM10 and PM2.5 in Table 3.2 were derived by this study from averaging values among the cities regardless of city population size. WHO (2016c) also published country-wide urban PM2.5 means (Table 3.3). These means are higher than the means shown in Table 3.2 because larger urban areas tend to have higher PM2.5 pollution. Table 3.3 better reflects PM2.5 pollution in urban areas in a country than Table 3.2 does. It also shows that Asia was among the most PM2.5 polluted regions of the world. Table 3.4 presents Asia's most polluted cities in terms of PM2.5 levels 10 times the WHO limit. Of the 27 cities, 18 are found in India including the top four most polluted cities. China is a distant second with six cities, followed by Pakistan with two cities and Bangladesh with one. The top 14 most polluted cities include 10 from India and four from China.

Variations within a country: the case of Chinese cities

The national annual average of PM2.5 and PM10 levels is an important indicator of air pollution in a country. In addition, it is important to understand the regional variations within a country, which may be substantial for a large country such as China. While the annual average of PM2.5 is 55 ug/m^3 in China, there is a large variation among the provinces (Table 3.5). The following examines such variations at the province level in China. The WHO database covers 194 Chinese cities with a total population of 863.2 million. While air pollution in Beijing has been well known, 85.9 million people in nearby Hebei and Tianjin live in worse air pollution, with Hebei's

Table 3.2 Particulate matter (PM10 and PM2.5) levels in Asian cities

Country or region	*# of cities covered*	*Data*	*PM10 annual means (µg/m³)*			*PM2.5 annual means (µg/m³)*		
		Year	*Maximum*	*Minimum*	*Mean*	*Maximum*	*Minimum*	*Mean*
Bangladesh	8	2014	191	64	140	106	37	78
China	194	2014	305	23	89	128	15	55
Hong Kong	1	2014			49			29
India	122	2012	329	11	107	176	6	58
Indonesia	1	2014			59			33
Japan	15	2012	35	19	28	19	10	15
Malaysia	6	2014	47	20	31	25	10	16
Myanmar	14	2012*	140	31	95	78	17	53
Nepal	1	2013			88			49
Pakistan	5	2010*	540	217	339	111	66	88
South Korea	16	2014	54	38	47	28	22	25
Singapore	1	2014			30			18
Sri Lanka	1	2011			64			36
Taiwan	19	2014	51	16	31	34	11	24
Thailand	23	2014	57	23	46	32	13	25

Notes:
[#] of cities: Number of cities included in the WHO database.
*= mode year. The year when the data were measured in different cities was 2009, 2012, and 2013 in Myanmar and 2009-2011 in Pakistan. A mode year is used here for the two countries.

Source: Compiled from WHO (2016a). Means were derived by author from averaging values among the cities regardless of city population size.

Notes: Where only one city in a country was reported, only the mean of the city is included.

PM2.5 level being 8 percent higher than Beijing's. About 162.1 million or 19 percent Chinese live in PM2.5 pollution seven times or more of the WHO limit, 353.5 million or about 41 percent live in six times or more of the WHO limit, 656.4 or over 76 percent live in five times or more of the WHO limit, and 856.6 million or over 99 percent Chinese live in three times or more of the WHO limit. Only Tibet and Hainan with less than 1 percent of the Chinese population live in PM2.5 levels compatible to that of Japan. At the city level, variations are even greater. About 44.8 million Chinese in six cities live in PM2.5 levels 10 to 12.8 times the WHO limit (Table 3.6). Nearly 74.6 million people in nearby Hebei, Tianjin, and Henan cities live in air pollution worse than Beijing. Nearly 94.2 million or 11 percent of the Chinese population live in air quality at or worse than the air in Beijing. Xingtai with PM2.5 at 128 is 50 percent worse than Beijing. About 402.5 million or 47 percent of Chinese live in cities where PM2.5 levels are six to 12.8 times the WHO limit.

None of the 194 Chinese cities met the WHO guidelines for PM10 or PM2.5. Sanya, Hainan, had the lowest PM10 at 23 µg/m3 followed by Yifan, Heilongjiang, at 24 µg/m3. Both cities also had the lowest PM2.5 level at 15 µg/m3 and 16 µg/m3 respectively. The 17 worst cities had PM10 levels over seven to 15 times exceeding WHO limit ranging from 144 to 305 µg/m3 were Shijiangzhuan, Jinan, Xingtai, Baoding, Xi'an, Zhengzhou, Handan, Xining, Hengshui, Taiyuan, Tangshan, Lanzhou, Tianjin, Chengdu, Urumqi, Hohhot, and Langfang. In terms of PM2.5 air pollution, six cities had levels over 10 to 12 times exceeding the WHO limit. They were Xingtai, Baoding, Shijiangzhuan, Handan, Hengshui, and Tangshan. The PM2.5 levels in Langfang,

Table 3.3 Annual mean concentrations of fine particulate matter (PM2.5) in urban areas (μg/m3) in Asian countries and WHO regions, 2014

Country/WHO region	*PM2.5 (μg/m³)*
Bangladesh	89.7
Nepal	75.7
India	73.6
Pakistan	68.7
China	61.8
Myanmar	56.7
Bhutan	39
Laos	33.6
Mongolia	33.5
North Korea	31.6
Viet Nam	28.7
Sri Lanka	28.6
South Korea	27.9
Philippines	27.6
Thailand	27.5
Cambodia	25
Indonesia	18.1
Singapore	17
Malaysia	16.7
Japan	13
African Region	36.7
Region of the Americas	14.5
South-East Asia Region	60.2
European Region	18.4
Eastern Mediterranean Region	62.9
Western Pacific Region	49.2
Global	38.4

Notes: Means were for all urban areas in the country.

Source: Compiled from WHO (2016a).

Cangzhou, Tianjin, Zhengzhou, Beijing, and Wuhan were from eight to nine times the WHO limit.

The most polluted tend to be lower and medium income manufacturing centers such as those in Hebei Province. This agrees with WHO findings that populations in less-developed cities are the most impacted by air pollution (WHO 2016b). On the other hand, less polluted areas tend to be more-developed cities such as those in Guangdong, Zhejiang, and Fujian. WHO (2016b) finds that 44 percent of cities in high-income countries meet the WHO air quality guidelines. However, none of the high-income Chinese cities do. Some of them are as wealthy as cities in high-income countries but severely polluted, such as Beijing, Tianjin, Wuhan, Tangshan, Zhengzhou, Nanjing, and Chengdu. Larger population centers also tend to be more likely to have higher pollution. However, there are many exceptions. Beijing and Tianjin more among the most developed and most polluted. Some of the least polluted Chinese cities are also less-developed, such as Zhanjiang, Sanya, Yilan, Haikou, Yuxi, Maoming, Yangjiang, Jiujiang, Chifeng, and Lhasa. Geographic factors also influence level of pollution. These factors include climate, particularly precipitation and wind direction and speed, topography, and distance to the coast.

Table 3.4 Most polluted Asian cities in terms of PM2.5 pollution 10 or more times the WHO limit

Country	*City*	*PM2.5 annual means (μg/m³)*	*PM10 annual means (μg/m³)*
India	Gwalior	176	329
India	Allahabad	170	317
India	Patna	149	167
India	Raipur	144	268
China	Xingtai	128	193
China	Baoding	126	190
India	Delhi	122	229
India	Ludhiana	122	228
China	Shijiazhuang	121	305
India	Kanpur	115	215
India	Khanna	114	213
India	Firozabad	113	212
India	Lucknow	113	211
China	Handan	112	169
Pakistan	Peshawar	111	540
India	Amritsar	108	202
India	Gobindgarh	108	201
Pakistan	Rawalpindi	107	448
China	Hengshui	107	161
Bangladesh	Narayangonj	106	191
India	Agra	105	196
China	Tangshan	102	153
India	Jodhpur	101	189
India	Dehradun	100	188
India	Ahmedabad	100	83
India	Jaipur	100	187
India	Howrah	100	186

Source: Compiled from WHO (2016a).

National air quality performance in Asian countries

The above discussion was based on outdoor air pollution data mainly from ground-based monitoring stations in selective spots in selective cities. Yale University (2016a) provides national level information on air quality including both urban and rural areas. It "ranks how well countries perform on protection of human health from environmental harm and protection of ecosystems." The Air Quality category is based on different indicators. They include average exposure to $PM_{2.5}$, health risk exposure to $PM_{2.5}$, percentage of the population exposed to $PM_{2.5}$ levels above WHO air quality guidelines, indoor solid fuel usage, and average concentration of NO_2 (Yale University 2016b). The Health Impacts indicator "assesses human health risks associated with unsafe water and sanitation as well as household and outdoor air quality" (Yale University 2016c). Different from the WHO data, the outdoor Air Quality indicators are mainly based on satellite-derived estimates (Yale University 2016d). Countries/regions are ranked by their performances and ten-year changes in each indicator as well as compared to their peers in terms of GDP per capita and their geographic neighbors.

Asian countries/regions tend to have lower rankings in air quality indicators (Table 3.7). Among the worst 21 countries/regions in PM2.5 exposure and exceedance, 12 are in Asia, with

Table 3.5 Population and particulate matter (PM2.5 and PM10) levels in Chinese provinces, 2014

Province level region	*Population*	*Number of stations*	*PM2.5 Annual mean (μg/m^3)*	*PM10 Annual mean (μg/m^3)*
Hebei	73	55	92	149
Tianjin	12.9	15	87	150
Beijing	19.6	14	85	108
Hubei	20.9	24	73	112
Henan	35.7	37	70	112
Subtotal	162.1			
Anhui	16.9	21	64	96
Shaanxi	33.1	51	64	120
Chongqing	28.8	17	61	106
Hunan	26.3	39	60	88
Jiangsu	86.1	92	60	92
Subtotal	353.5			
Jilin	12.1	17	57	103
Liaoning	35.2	62	56	86
Zhejiang	57.4	57	54	90
Guangxi	16.7	22	52	83
Shanghai	23	10	52	84
Shanxi	7.6	12	52	78
Sichuan	41.1	41	52	83
Xinjiang	4.1	15	52	94
Shandong	105.7	98	51	82
Subtotal	656.4			
Guizhou	10.4	15	49	80
Jiangxi	9.8	17	45	88
Ningxia	2.7	10	44	90
Heilongjiang	22.1	29	41	65
Gansu	5.8	10	40	83
Neimenggu	11.8	23	40	81
Guangdong	94	91	39	61
Shenzhen	10.4	11	34	61
Fujian	18.8	14	33	58
Yunnan	14.6	12	32	58
Subtotal	856.6			
Tibet	0.6	6	24	64
Hainan	2.7	7	19	35
Subtotal	3.3			
China	863.2			

Sources: PM10 and PM2.5 data were compiled from WHO (2016a). Population data are from National Bureau of Statistics of China (2012).

China, Bangladesh, India, Nepal, and Pakistan as the worst five. Other countries do not rank high except for Mongolia and the Philippines in PM2.5 exposure and Singapore and Mongolia being number one in PM2.5 exceedance. Asian countries/regions do not rank well in terms of exposure to NO_2 which tends to be associated with more developed economies. It is not surprising that South Korea, Japan, Singapore, and Taiwan were among the worst. However, it is a surprise that China as a developing country ranked 176, the fourth worst in the world and second only to

Table 3.6 Most polluted Chinese cities, 2014

Province level region	*City*	*2010 census population (million)*	*PM2.5 Annual mean, μg/m^3*	*PM10 Annual mean, μg/m^3*
Hebei	Xingtai	7.1	128	193
Hebei	Baoding	11.2	126	190
Hebei	Shijiazhuang	10.2	121	305
Hebei	Hengshui	4.3	112	169
Hebei	Tangshan	7.6	107	161
Hebei	Langfang	4.4	102	153
Subtotal		44.8		
Hebei	Cangzhou	7.1	96	144
Hebei	Shouguang	1.1	88	133
Tianjin	Tianjin	12.9	87	150
Henan	Zhengzhou	8.6	86	171
Subtotal		74.6		
Beijing	Beijing	19.6	85	108
Subtotal		94.2		
Hubei	Wuhan	9.8	80	124
Henan	Anyang	5.2	79	119
Anhui	Hefei	5.7	79	115
Hebei	Shouguang	1.1	78	117
Hubei	Jingzhou	5.7	74	112
Hunan	Changsha	7	74	94
Jiangsu	Nanjing	8	72	137
Liaoning	Shenyang	8.1	72	129
Sichuan	Chengdu	14	71	150
Jilin	Harbin	10.6	71	119
Henna	Kaifeng	4.7	70	106
Hubei	Yichang	4.1	70	106
Hubei	Yangquan	1.4	70	105
Henan	Pingdingshan	4.9	70	105
Hunan	Xiangtan	2.8	70	105
Shaanxi	Xi'an	8.5	70	189
Hunan	Zhuzhou	3.9	69	105
Shandong	Laiwu	1.3	68	103
Henan	Jiaozuo	3.5	68	103
Jiangsu	Jiangyin	1.6	68	102
Jiangsu	Suqian	4.7	68	102
Shaanxi	Weinan	5.3	68	102
Shaanxi	Changzhi	3.3	67	101
Shaanxi	Taiyuan	4.2	67	157
Jiangsu	Wuxi	6.4	67	101
Jiangsu	Xuzhou	8.6	66	100
Jiangsu	Zhenjiang	3.1	66	99
Jiangsu	Changzhou	4.6	65	99
Shaanxi	Xianyang	5.1	65	98
Guangxi	Liuzhou	3.8	65	98
Liaoning	Anshan	3.6	65	98
Jiangsu	Huai'an	4.8	65	98

(*Continued*)

Table 3.6 (continued)

Province level region	*City*	*2010 census population (million)*	*PM2.5 Annual mean, μg/m³*	*PM10 Annual mean, μg/m³*
Shaanxi	Baoji	3.7	65	98
Jiangsu	Jurong	0.6	65	97
Jiangsu	Yangzhou	4.5	65	97
Xinjiang	Urumqi	3.1	64	146
Sichuan	Zigong	2.7	64	97
Zhejiang	Shaoxing	4.9	64	105
Jiangsu	Suzhou	10.5	64	97
Shaanxi	Tongchuan	0.8	64	97
Henan	Sanmenxia	2.2	64	96
Liaoning	Changchun	7.7	64	130
Shandong	Liaocheng	5.8	63	96
Zhejiang	Jinhua	5.4	63	99
Zhejiang	Huzhou	2.9	63	111
Shanxi	Linfen	4.3	62	94
Qinghai	Xining	2.2	62	163
Chongqing	Chongqing	28.8	61	106
Zhejiang	Taizhou	6	61	82
Anhui	Wuhu	2.3	61	92
Jiangsu	Lianyungang	4.4	61	92
Zhejiang	Hangzhou	8.7	61	106
Shandong	Heze	8.3	60	91
Hebei	Qinhuangdao	3	60	91
Jiangsu	Zhangjiagang	1.2	60	91
Jiangsu	Nantong	7.3	60	90
Anhui	Fuyang	7.6	60	90
Total		402.5		

Sources: PM10 and PM2.5 data were compiled from WHO (2016a). Population data are from National Bureau of Statistics of China (2012).

South Korea in Asia. Myanmar and Bhutan had the highest ranking in Asia, in consistence with their level of economic development. Household air quality rankings are closely related to level of economic development. Japan, South Korea, and Singapore were the world best while most Asian countries rank poorly, with Laos, Myanmar, Cambodia, Bangladesh, Nepal, and Sri Lanka being the worst in Asia. The air quality category ranking was based on the above indicators. The world's worst eight countries in air quality are all in Asia. Thailand, Bhutan, and Taiwan are not doing well either with their rankings above 160. Only four of the 20 countries/regions were ranked above 100. Singapore, the Philippines, and Mongolia are better than their Asian neighbors but still ranked below the world's top 50. The poor air quality rankings reflect the low rankings in PM2.5 exposure and exceedance, except for exceedance in Singapore which is ranked number 1. Since the Health Impacts indicator refers to impacts by both air and water pollution, it may not agree with air pollution rankings. For example, Malaysia and Japan were ranked higher in water pollution performance so its Health Impacts ranking is better than its air quality ranking. The worst rankings are Bangladesh, Myanmar, Nepal, Cambodia, and India.

A country/region's level of economic development is commonly believed to be associated with certain level of air pollution. Such a belief calls for comparison among countries/regions at

Table 3.7 Air quality and health impacts rankings of selective Asian countries/regions among 180 countries/regions worldwide, 2014

Country or Region	*Exposure to PM2.5*	*PM2.5 Exceedance**	*Exposure to NO_2*	*Household Air Quality*	*Air Quality*	*Health Impacts***
China	180	179	176	116	179	95
Bangladesh	179	178	107	151	180	150
India	178	178	110	135	178	134
Nepal	177	177	61	146	177	141
Pakistan	176	176	105	125	175	123
South Korea	174	174	178	1	173	103
Laos	173	174	75	162	176	127
Viet Nam	170	165	103	119	170	93
Myanmar	168	168	40	156	174	143
Thailand	166	170	118	104	167	85
Taiwan	162	160	159	101	161	84
Bhutan	160	173	40	112	163	91
Cambodia	114	127	61	153	148	137
Malaysia	110	155	133	54	117	42
Sri Lanka	109	140	52	141	140	114
Japan	95	133	172	1	104	57
Singapore	93	1	163	1	54	63
Indonesia	74	122	101	113	92	78
Philippines	30	78	75	123	61	108
Mongolia	23	1	61	131	65	111

Notes:
*= the percentage of the population exposed to PM2.5 levels above the WHO limit. 179 was the worst ranking in 2016 Report.
**Impacts by both air and water pollution.

Source: Compiled from Yale University (2016c).

the same level of development in order to be fair. The result shows that majority Asian countries/regions compare rather unfavorably to their GDP peer set (Table 3.8). China appears to be the worst in the outdoor air quality comparison, followed by Bangladesh and India. In terms of Exposure to PM2.5, China and Bangladesh were 97.23 percent and 92.79 percent below their peers. India, Nepal, and Pakistan were all over 80 percent below their peers. On the other hand, six of the 20 countries/regions compare favorably with their GDP peers, such as Mongolia and the Philippines. In terms of PM2.5 exceedance, Bangladesh, China, and India were each 100 percent below their peers, followed by Nepal and Pakistan. Only three countries compared favorably to their GDP peers, including Singapore, Mongolia, and the Philippines. It was a surprise that Bhutan is compared unfavorably by 66.94 percent to its peers. The country has little manufacturing at low level of economic development. It is reasonable to assume that it has been affected by pollution from its southern neighbors such as India and Bangladesh. In the matter of Exposure to NO_2, South Korea was 100 percent below its GDP peers, followed by China at 80.68 percent. Six countries compared favorably including Myanmar, Bhutan, and Sri Lanka. With regard to Household Air Quality, half of the 20 countries/regions compared favorably to their GDP peers, with Nepal at 100 percent and Cambodia at 61.27 percent. On the other hand, Laos and Myanmar were over 50 percent below their peers. Pertaining to the Air Quality category, China and Bangladesh were over 70 percent worse than countries at the same economic development level. India, Laos, Nepal, and Pakistan were all over 50 percent below their peers in the comparison.

Table 3.8 Air quality and health impacts of selective Asian countries/regions as compared individually to countries/regions at the same level of GDP per capita (%), 2014

Country or Region	*Exposure to PM2.5*	*PM2.5 Exceedance*	*Exposure to NO_2*	*Household Air Quality*	*Air Quality*	*Health Impacts**
China	−97.23	−100	−80.68	−18.12	−71.65	−11.34
Bangladesh	−92.79	−100	−11.27	−37.24	−70.84	−28.8
India	−89.71	−100	−12.63	−8.72	−62.55	−12.89
Nepal	−83.49	−93.79	−1.35	100	−55.27	70.41
Pakistan	−81.7	−87.16	−10.61	−1.38	−53.88	−3.1
South Korea	−58.2	−73.52	−100	1.94	−44.26	−21.89
Laos	−52.13	−73.84	1.14	−67.17	−56.71	−7.02
Viet Nam	−41.56	−46.69	−9.95	5.94	−26.94	17.72
Thailand	−39.26	−60.65	−6.38	−8.54	−32.93	−6.39
Myanmar	−37.71	−53.32	6.78	−50.68	−40.85	−21.31
Taiwan	−28.31	−38.26	−18.13	−13.57	−25.31	−13.4
Bhutan	−20.25	−66.94	6.78	15.13	−22.57	19.51
Malaysia	−5.74	−34.56	−17.56	8.4	−11.07	11.63
Cambodia	−1.17	−17.28	−1.35	61.27	−0.68	78.38
Japan	1.51	−8.51	−54.13	1.94	−4.92	−2.69
Sri Lanka	2.17	−15.51	5.68	−16.53	−7.96	3.46
Singapore	2.45	27.55	−27.26	1.94	7.53	−4.91
Indonesia	17.83	−1.03	−8.65	12.08	7.21	27.56
Philippines	27.15	22.92	1.14	0.75	15.79	7.57
Mongolia	28.59	26.03	4	−6.39	15.65	5.54

Notes: *Impacts by both air and water pollution. The percentages range from positive 100 to negative 100.

Source: Compiled from Yale University (2016c).

The Philippines and Mongolia compared most favorably with their peers. In reference to the Health Impacts category, Bangladesh, South Korea, and Myanmar were the least favorably compared to their GDP peers while Cambodia and Nepal had the most favorably comparison.

With regard to PM2.5 exposure, 12 of the 20 countries/regions compared unfavorably to their neighbors in the same EPI Regions (Table 3.9). China was the worst, 97.13 percent below its neighbors. Bangladesh and India were over 80 percent worse than their neighbors. On the other hand, Sri Lanka, Bhutan, Mongolia, and the Philippines compared very favorably to their neighbors. The worst countries China, Bangladesh, and India were all 100 percent worse than their neighbors in the PM2.5 exceedance comparison. Nepal, South Korea, Laos, and Pakistan were over 70 percent worse than their neighbors. On the opposite side, Sri Lanka, Mongolia, Singapore, and the Philippines compared very favorably to their neighbors. South Korea was the worst when compared to its neighbors in Exposure to NO_2, followed by China, Japan, Singapore, and Taiwan. Half of the countries/regions, all of them less-developed, compared favorably to their neighbors. Yet, the less-developed economies tended to compare very unfavorably to their neighbors in Household Air Quality, except for Bhutan. More-developed economies tended to do better in Household Air Quality. In the overall Air Quality category, China was the worst, 68.28 percent worse than its neighbors, followed by Laos, Bangladesh, and India. On the other hand, Sri Lanka was nearly 37 percent higher compared to its neighbors. In terms of Health Impacts, most less-developed economies did not compare well with their neighbors. The exceptions were Bhutan, Malaysia, and Sri Lanka.

Table 3.9 Air quality and health impacts of selective Asian countries/regions as compared to their neighbors in the EPI Regions (%), 2014

Country or Region	*Exposure to PM2.5*	*PM2.5 Exceedance*	*Exposure to NO_2*	*Household Air Quality*	*Air Quality*	*Health Impacts**
China	−97.13	−100	−79.78	1.26	−68.28	−1.96
Bangladesh	−87.75	−100	−11.96	−28.92	−56.62	−25.59
India	−82.52	−100	−13.31	3.38	−44.3	−8.96
Nepal	−71.52	−84.44	3.19	−12.9	−40.79	−15.69
Pakistan	−68.92	−71.61	−11.31	11.71	−31.4	1.28
South Korea	−57.46	−72.43	−100	37.12	−39.38	−6.17
Laos	−54.23	−72.43	18.17	−69.59	−56.78	−21.75
Viet Nam	−44.12	−43.82	5.22	−1.88	−27.06	−0.93
Thailand	−37.06	−56.05	−1.99	13.12	−24.98	3.52
Taiwan	−27.03	−35.7	−41.29	16.25	−18.77	4.02
Cambodia	−4	−1.22	21.52	−43.28	−11.75	−28.94
Malaysia	−2.34	−26.91	−13.69	34.07	−0.52	23.45
Japan	3.32	−4.73	−67.1	37.12	3.41	16.89
Singapore	4.28	32.82	−47.83	37.12	16.95	14.23
Myanmar	5.81	3.21	5.95	−44.14	−12.01	−17.76
Indonesia	12.68	4.3	6.74	3.81	7.04	7.35
Philippines	21.59	29.54	18.17	−6.69	15.61	−9.47
Mongolia	22.97	32.82	21.52	−13.3	15.48	−11.18
Bhutan	35.47	−26.91	5.95	30.4	15.17	24.91
Sri Lanka	73.55	86.81	4.85	−5.46	36.9	8.14

Note: *Impacts by both air and water pollution.

Source: Compiled from Yale University (2016c).

Historical trends

From 2005 to 2014, PM2.5 Exposure increased in all countries/regions except for Japan and the Philippines (Table 3.10). The largest increases were by 68 percent to 84 percent in China, India, and Bangladesh. However, PM2.5 Exceedance increased in only five countries while most countries/regions experienced a declining trend in the 10 years. China's Exposure to NO_2 increased by 54.36 percent in ten years, the largest increase in Asia. The increases in other countries were small. Japan had a 58 percent decrease in ten years followed by Taiwan with a 45 percent decrease. Most countries improved their Household Air Quality by 90 percent to 100 percent in the 10 year period. The overall Air Quality increased in most countries/regions also, possibly benefiting from Household Air Quality improvement. Myanmar and Bangladesh experienced the largest decrease in overall Air Quality. The same trend also happened to Health Impacts with most countries/regions experienced improvement. Yet, Singapore, Malaysia, and Japan suffered some losses.

Historical data on pollution measurements from Yale University (2016e) reflect changing patterns in different countries/regions. Based on the data, means were derived for the historical periods (Table 3.11). With 78.4 percent of its population exposed to PM2.5 levels above the WHO limit, China is the highest in the world from 2000 to 2014. South Asian countries also had high levels except for Sri Lanka and Bhutan. Only six countries met the WHO annual limit. Furthermore, the worst seven countries in the world are in Asia, from China to North Korea. Again, South Asian countries also had a very depressing situation with Sri Lanka and

Table 3.10 Ten-year change (%) in air quality and health impacts of selective Asian countries/regions, 2014

Country or Region	*Exposure to PM2.5*	*PM2.5 Exceedance*	*Exposure to NO_2*	*Household Air Quality*	*Air Quality*	*Health Impacts**
Bangladesh	−83.57	0	−7.37	49.48	−18	−1.29
India	−72.84	0	−1.94	74.74	4.97	5.1
China	−67.79	0	−54.36	100	53.22	20
Nepal	−58.73	100	−0.77	95.82	13.98	30.36
Laos	−45.42	100	−1.97	−6.14	−9.38	14.73
Myanmar	−45.13	−36.18	−2.09	38.42	−25.73	12.45
Viet Nam	−36.51	83.51	−5.99	100	20.64	25.31
Thailand	−36.29	90.5	1.66	100	18.94	−0.63
Bhutan	−27.56	−42.64	−1.13	100	−1.04	15.93
Pakistan	−20.6	100	−4.92	100	51.36	20.99
Cambodia	−18.29	−2.27	−1.77	90.28	−0.02	24.61
Malaysia	−15.29	−0.7	3.49	98.56	15.71	−7.38
Sri Lanka	−15.18	−32.96	−0.19	87.64	−8.4	11.07
Taiwan	−10.86	100	44.97	−0.89	28.65	7.01
Singapore	−8.54	0	13.14	95	16.46	−13.66
South Korea	−6.1	100		95	77.15	−1.2
Indonesia	−3.93	15.5	7.21	100	20.7	6.86
Mongolia	−0.2	0	−2.28	96.28	11.28	18.56
Philippines	1.41	24.51	0.74	83.59	21.38	−0.45
Japan	5.03	56.86	57.9	95	45.1	−4.29

Note: *Impacts by both air and water pollution.

Source: Compiled from Yale University (2016e).

Bhutan as the exceptions. Singapore and Mongolia were very successful in dealing with this issue. Similar situation is true in regard to PM2.5 Exceedance, with Asian countries took the worst seven places. The situation is a little better with PM2.5 Health Risk Exposure from 1990 to 2013. China is the worst in Asia but the third worst in the world. South Asian countries followed, except for Sri Lanka and Bhutan. Mongolia and the Philippines had the lowest risk exposure. With regard to NO_2 Exposure, more-developed economies such as South Korea, Hong Kong, and Japan suffered high level of exposure from 1997 to 2011. The data again indicate that China experienced higher level of NO_2 pollution than would have been expected at its level of economic development. Most developing countries, such as Bhutan and Myanmar, had low levels of exposure, constant with their level of economic development.

Eight countries/regions were selected from Table 3.11 to illustrate the historical trends in each air quality indicator. In order to pay attention to the relationship between level of development and air quality, the figures included four more-developed economies: Japan, South Korea, Taiwan, and Hong Kong. In the case of PM2.5 Health Risk Exposure for which Hong Kong had no data, Singapore was used instead. They also include four less-developed economies: China, India, Pakistan, and Bangladesh. It should be noted that the more-developed economies are all Island countries/regions. Their air quality should have been favorably affected by their geographic location that is associated with stronger wind, ocean influence, and more precipitation.

Table 3.11 Asian countries/regions ranked in the world by their means of air pollution indicators

Country or region	*PM2.5 Exposure 2000–2014*	*Country or region*	*PM2.5 Exceedance 2000–2014*	*Country or region*	*PM2.5 Health Risk* 1990–2013*	*Country or region*	*NO_2 Exposure 1997–2011*
1. China	45.1	1. China	0.784	3. China	0.656	3. South Korea	7.06
2. India	28.4	2. Pakistan	0.686	7. Pakistan	0.621	4. Hong Kong	6.37
3. Pakistan	27.9	3. Nepal	0.656	10. Bangladesh	0.6	9. Japan	4.2
4. Nepal	27.3	4. India	0.642	15. India	0.579	16. China	3.29
5. Bangladesh	24.8	5. Bangladesh	0.614	16. Nepal	0.576	18. Taiwan	3.19
6. South Korea	21.5	6. South Korea	0.529	22. South Korea	0.527	59. Malaysia	1.03
7. North Korea	19.8	7. North Korea	0.482	40. North Korea	0.451	70. Thailand	0.71
10. Laos	16.7	10. Hong Kong	0.409	52. Bhutan	0.417	82. India	0.51
11. Hong Kong	16.6	15. Laos	0.379	59. Viet Nam	0.408	90. Bangladesh	0.41
14. Viet Nam	15.9	24. Taiwan	0.333	65. Singapore	0.397	91. Pakistan	0.4
26. Taiwan	14.5	28. Thailand	0.32	70. Taiwan	0.391	93. Viet Nam	0.38
32. Thailand	13.7	29. Viet Nam	0.319	73. Myanmar	0.388	101. Philippines	0.28
39. Bhutan	12.6	34. Bhutan	0.288	83. Laos	0.372	120. Laos	0.21
45. Japan	12.3	51. Japan	0.2	85. Thailand	0.367	123. Nepal	0.19
53. Myanmar	11.4	53. Myanmar	0.192	87. Japan	0.362	129. Cambodia	0.17
72. Malaysia	9.6	65. Malaysia	0.14	111. Sri Lanka	0.301	134. Sri Lanka	0.15
84. Indonesia	8.5	77. Indonesia	0.11	114. Cambodia	0.29	157. Myanmar	0.11
85. Cambodia	8.5	87. Cambodia	0.062	116. Indonesia	0.285	158. Bhutan	0.1
91. Sri Lanka	7.8	89. Sri Lanka	0.055	119. Malaysia	0.276		
113. Philippines	6.4	98. Philippines	0.035	149. Philippines	0.151		
153. Singapore	4.6	147. Mongolia	0.001	157. Mongolia	0.121		
		211. Singapore	0				

Note: *PM2.5 Health Risk Exposure is a unitless measurement from 0 to 1 with 1 being the highest risk.

Source: Compiled from Yale University (2016e).

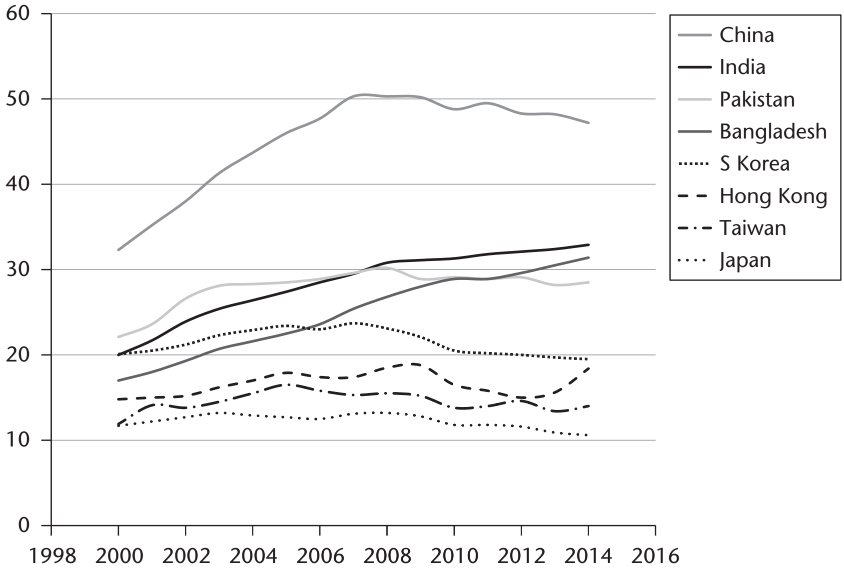

Figure 3.1 Annual mean PM2.5 Exposure in Asian countries/regions 2000–2014

Source: Compiled from Yale University (2016c).

Pertaining to annual PM2.5 Exposure, the less-developed economies all experienced an increasing trend from 2000 to 2014 (Figure 3.1). China experienced the fastest increasing trend with leveling off and slight decline in recent years. Leveling off and a slight decline also happened to Pakistan, while India and Bangladesh had a steady growing trend. The more-developed economies tend to have lower levels than the less-developed. South Korea, Taiwan, and to some lesser extent, Japan experienced a slight rise first, followed by a slight decline. Hong Kong was a little different with a recent rise. In regard to the proportion of population exposed to PM2.5 levels exceeding the WHO limit, the four less-developed countries had a higher rate than the more-developed (Figure 3.2). China and Pakistan had a leveling off while India and Bangladesh continue to rise. The more-developed economies experienced a rise and fall while maintaining low levels, with Hong Kong and South Korea having an increase in 2014. Japan's trend was rather flat, indicating a sustained low level. Comparing Figures 3.1 and 3.2, it may be argued that more proportion of Chinese suffered from PM2.5 pollution while the intensity of the pollution had leveled off in recent years. The pollution has become more widely spread while intensity slightly lowered.

In respect to PM2.5 Health Risk Exposure, the four less-developed countries had a high risk with a rising trend (Figure 3.3). The more-developed economies had a low risk with a slight declining trend, except for Singapore with an inverted shape. Its risk was higher than any other countries in the early 1990s but quickly bottomed to the lowest level and then increased again. Trends in NO_2 Exposure were very different among the countries/regions (Figure 3.4). China's NO_2 pollution caught up very quickly, overtaking Taiwan's in the early 2000 and Japan's in the late 2000s. The other less-developed countries all had very low level of NO_2 pollution with a slight increase. The more-developed economies experienced a declining trend starting in the late 1990s to mid-2000s. China was a less-developed country with NO_2 pollution at the level of more-developed economies. Its increasing trend leveled off from 2010 to 2011.

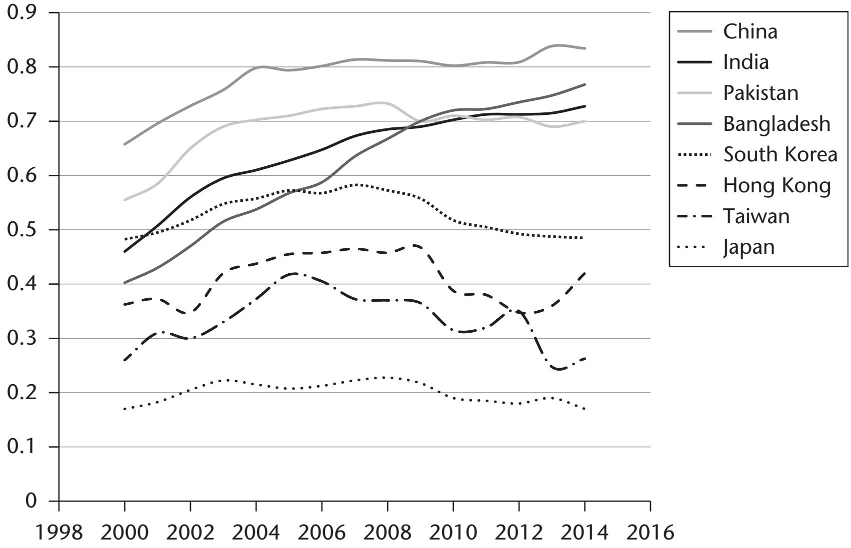

Figure 3.2 Annual mean PM2.5 Exceedance in Asian countries/regions 2000–2014

Source: Compiled from Yale University (2016c).

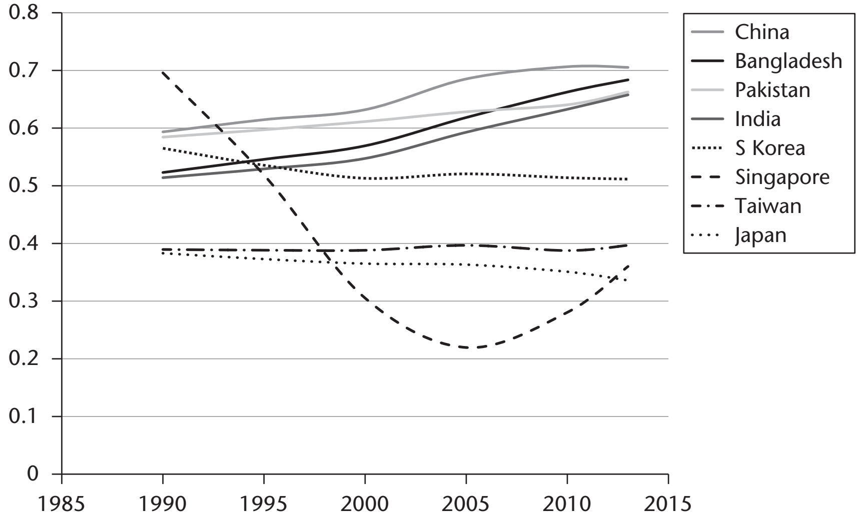

Figure 3.3 Annual mean PM2.5 Health Risk in Asian countries/regions 1990–2014

Source: Compiled from Yale University (2016c).

Air pollution in Asia may be the worst globally and historically

The above discussion indicates that the exact extent of pollution varies by sources of data, possibly due to different methods of measurement by the same or different organizations. For example, the WHO reported that annual mean PM2.5 for urban China was 61.8 $\mu g/m^3$ (Table 3.3). That was higher than what Rohde and Muller (2015) reported, noting 52 $\mu g/m^3$ as the population-weighted average based on station-measured data in 190 cities. Yale University

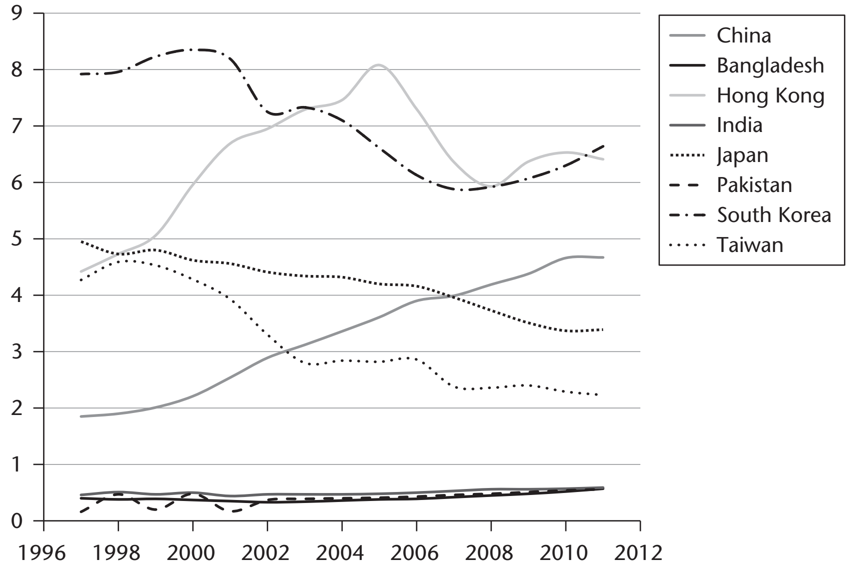

Figure 3.4 Annual mean NO_2 Exposure in Asian countries/regions 1997–2011

Source: Compiled from Yale University (2016c).

reported 45.13 μg/m^3 for both urban and rural areas. However, both the WHO and Yale University data suggested similar patterns and trends. Asia has been the worst hit by air pollution, particularly in terms of deadly PM2.5 exposure, despite the fact that some Asian countries such as Japan and Singapore have much lower levels of pollution. India, China, Pakistan, and Bangladesh are the worst in Asia. Furthermore, the country-wide averages may hide disparities in air pollution. Levels of pollution also varied greatly within large countries such as China, where about 44.8 million people live in PM2.5 polluted air 10 times or more the WHO limit. Eastern China, particularly areas around Beijing and Tianjin, has been the worst hit by PM2.5 pollution. Geographic factors such as climate and topography affect the level of air pollution, in addition to population and type of economy. Air pollution has also been reported to be the worst in the northern parts of India, Pakistan, and Bangladesh (WHO 2016d).

National level data from Yale University provided additional insight into air quality and pollution in Asia in a global context. Asian countries/regions tended to receive lower rankings in PM2.5 Exposure and Exceedance with China, Bangladesh, India, Nepal, and Pakistan ranked as the worst in the world. This generally coincides with the findings based on the WHO data. Furthermore, Asian countries/regions also ranked low in NO_2 Exposure, which tends to be associated with more-developed economies. This means that these countries/regions suffer more from NO_2 pollution than expected at their level of development. China is the worst in this aspect. Asia is also worst in terms of overall air quality based on outdoor and indoor pollution. Asia is home to the world's worst eight countries in terms of air quality. Asian countries/regions compare rather poorly to countries at similar levels of economic development, with China as the worst. As air pollution is not restricted by national borders, it is reasonable to assume that some less-developed countries such as Bhutan have been negatively affected by air pollution from their neighbors.

From 2005 to 2014, China, India, and Bangladesh led the increase in PM2.5 Exposure. Indeed, the worst seven countries in the world in terms of PM2.5 Exposure are located in Asia. There were also substantial increases in other Asian countries/regions except for Japan and the

Philippines. The good news is that most Asian countries/regions experienced a decrease in PM2.5 Exceedance. Historical data from 2000 to 2014 indicate that China is the worst in the world in PM2.5 Exceedance, as 78.4 percent of its population was exposed to PM2.5 above the WHO limit. The historical patterns appear to be different between more and less-developed economies. Less-developed economies tended to experience high levels and an increasing trend in PM2.5 Exposure while the more-developed economies tended to have lower levels with a rising and falling trend. Similar trends exist in terms of PM2.5 Exceedance and PM2.5 Health Risk Exposure.

Air pollution is a threat to public health in Asia

Air pollution is a threat to sustainability in several aspects, including its impact on climate change, human health, social justice, and economic equality and well-being. This study focuses on its threat to public health. The WHO just published its global assessment of disease burden due to environmental risks in 2012 (Prüss-Ustün et al. 2016). The WHO report and accompanying dataset provide a rare opportunity to compare environmental health in Asian countries. China and India each lost nearly three million people to environmental risks, contributing to 30 percent of all deaths in the two countries (Table 3.12). That was 30 percent higher than the world average

Table 3.12 Burden of disease from environmental risks, Asian countries, 2012

Country	*Total (000s)*	*% deaths*	*Total (000s)*	*% DALYs*	*Age-standardized deaths/100,000*	*Age-standardized DALYs/100,000*
Bangladesh	201.53	23	11346.44	22	189	8,520
Bhutan	1.26	26	70.26	25	225	10,574
Cambodia	21.01	25	1263.56	22	173	9,051
China	2986.68	30	95968.22	26	199	6,408
India	2911.67	30	133618.4	25	315	12,119
Indonesia	349.87	23	16163.07	21	198	7,479
Japan	131.28	11	4222.25	13	41	2,110
Laos	14.91	32	927.29	31	321	14,524
Malaysia	25.94	18	1427.05	19	123	5,504
Mongolia	5.17	27	238.72	24	309	10,665
Myanmar	109.24	25	5271.27	23	277	11,255
Nepal	46.69	25	2369.45	23	251	10,129
North Korea	70.45	31	2454.7	27	310	10,122
Pakistan	331.18	25	19468.4	23	258	11,385
Philippines	123.46	22	7024.14	21	206	8,809
Singapore	3.11	13	120.46	13	47	1,900
South Korea	37.96	14	1482.86	14	58	2,461
Sri Lanka	34.92	25	1337.63	22	169	6,265
Thailand	93.82	19	3941.21	18	124	5,389
Viet Nam	129.27	25	5748.16	23	158	6,764
Total	7629.42		596412.2			

Notes: DALY refers to Disability-Adjusted Life Year. One DALY can be thought of as one lost year of "healthy" life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability. DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences (Prüss-Ustün et al. 2016).

Source: Compiled from Prüss-Ustün et al. (2016).

of 23 percent. Only a few Asian countries were below the world average, including Japan, Singapore, South Korea, Malaysia, Thailand, and the Philippines. Laos was the worst at 32 percent. In addition, environmental risks contributed to lost years of healthy life as indicated by Disability-Adjusted Life Years (DALYs). The percentages of DALYs varied among the Asian countries but were closely associated with percentages of deaths. The age-standardized death rates attributable to environmental risks were highest in Laos, India, North Korea, and Mongolia, with over 300 per 100,000. Japan, Singapore, and South Korea had the lowest rates of death due to environmental risks. The ratio of such deaths between Laos and Japan is nearly eight times, which could be used to argue for an association between economic development and environmental health. However, there is no justification to degrade environmental health in the name of development.

Environmental health risks include more than air pollution. Yet air pollution, especially PM2.5 pollution, is one of the most deadly risks to human health (Table 3.13). Beelen et al. (2014) found that naturally-caused mortality was associated with long-term exposure to PM2·5 in European countries, even if the air pollution level was well below the mean annual limit of 25 $\mu g/m^3$. Developing countries have been suffering from severe air pollution which is a major cause of health problems, resulting in between 1.2 to 2 million premature deaths a year in China alone (Yang et al. 2013; WHO 2014b). Rohde and Muller (2015) found that Eastern China, where most of the population resides, was the hardest hit by air pollution. They estimated that unhealthy air affected 92 percent of China's population, if US standards were applied.

Among the 21 countries for which data were available, air pollution is the most deadly in North Korea, contributing to 83.59 percent of all environment-attributed deaths (Table 3.13). China is second only to North Korea, with air pollution being responsible for 163.1 deaths per 100,000 population and over three-fourths of all environmentally-attributed deaths. Air pollution also causes over 70 percent of all environmentally attributed fatalities in Mongolia and Sri Lanka. On the other hand, four Asian countries, Singapore, Malaysia, South Korea, and Japan, are doing well, with air-pollution causing fewer than 25 deaths per 100,000 population and less than 37 percent of all environmentally attributed deaths. The total population for the 21 Asian countries is 3,931.8 million, about 54 percent of the global population. However, these countries contribute 4.917 million deaths, with 73 percent of the global deaths attributed to air pollution. China alone contributes 34 percent of the world deaths attributed to air pollution. The mortality rate of the 21 Asian countries is 125 per 100,000 population. That is 5.76 times the rate for the Americas, 2.1 times the rate for the Eastern Mediterranean Region, 93 percent higher than the rate for the European Region, and 61 percent higher than that of the African Region.

Is there an environmental Kuznets curve for air pollution in Asia?

Yale's 2016 EPI Report suggests that the relationship between Environmental Health and GDP per capita is strongly positive, possibly due to improvement in public health as countries develop (Yale University 2016a). It also pointed out that something other than economic development alone may also be critical in achieving environmental results. An EKC relationship was found in emissions in 14 Asian countries (Apergis and Ozturk 2015) and in NO_2 emissions in Indian cities (Sinha and Bhattacharya 2016). A few papers have attempted to explore if an EKC exists in PM2.5 pollution. Keene and Deller (2015) found such an EKC for the United States with the turning point occurring between US $27,100 and US $28,200 per capita income for PM2.5 emissions and US $24,000 and US $25,500 for PM2.5 concentration. However, Stern and van Dijk (2016) found that economic growth had relatively small effects on the variation in

Table 3.13 Mortality rate (per 100,000 population) and total deaths attributed to household and ambient air pollution versus total environment attributable deaths, Asian countries, WHO regions, and the world total, 2012

Country	*Deaths/100,000*	*Total deaths attributed to air pollution* (000s)*	*As % of total environment attributable deaths***
North Korea	234.1	58.89	83.59
China	163.1	2257.18	75.57
Mongolia	132.2	3.91	75.62
India	130	1704.37	58.54
Myanmar	127.4	68.66	62.86
Sri Lanka	119.4	24.73	70.84
Laos	107.6	7.32	49.08
Nepal	104.2	29.71	63.64
Pakistan	88.8	167.77	50.66
Viet Nam	84	78.5	60.72
Indonesia	83.9	216.1	61.76
Philippines	82.7	83.28	67.45
Cambodia	71.4	11.12	52.93
Bangladesh	68.2	109.8	54.48
Thailand	65.3	44.38	47.3
Bhutan	59.9	0.46	36.87
Japan	24.2	30.63	23.33
South Korea	23.7	11.92	31.4
Malaysia	22.4	6.79	26.19
Singapore	20.5	1.15	36.94
Subtotal	125	4916.67	64.44
African Region	77.4	765.62	
Region of the Americas	21.7	214.11	
South-East Asia Region	117.1	2257.89	
European Region	64.9	590.62	
Eastern Mediterranean Region	59.3	381.76	
Western Pacific Region	134.8	2500.71	
World	91.7	6706.03	53.12

Notes:
*Calculated by author based on the 2015 population published by WHO (2016c).
**Calculated by author based on Table 3.12.

Source: Compiled from WHO (2016c) and Prüss-Ustün et al. (2016).

PM2.5 pollution globally. Han et al. (2016) was unable to find such an EKC for Beijing, which they believed had not reached the turning point of an EKC.

To test the relationship between economic development and air pollution, the annual mean PM2.5 and PM10 measurements were plotted against GDP per capita in 131 cities in China. The results indicated no EKC or any relationship in either PM2.5 pollution (Figure 3.5) or PM10 pollution (Figure 3.6). The relationship was also tested using the EPI data for the Asian countries/regions in Table 3.11, with GDP per capita data for the Asian countries/regions obtained from the World Bank (2016) and CIA (2016). No associations were detected for the PM2.5 Exposure (Figure 3.7), PM2.5 Exceedance (Figure 3.8), or PM2.5 Health Risk (Figure 3.9). However, an EKC was found for NO_2 pollution (Figure 3.10).

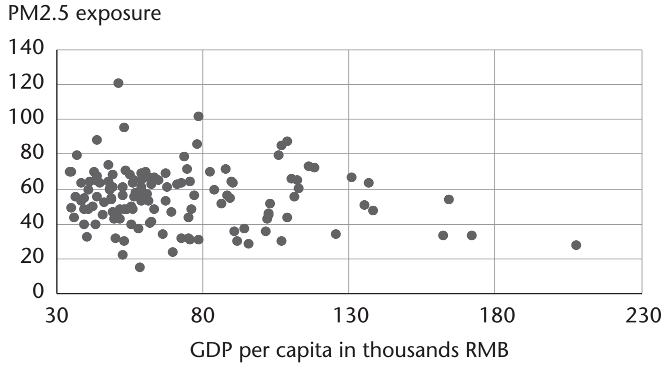

Figure 3.5 Annual mean PM2.5 Exposure and GDP per capita in Chinese cities, 2014

Source: Compiled from Yale University (2016e).

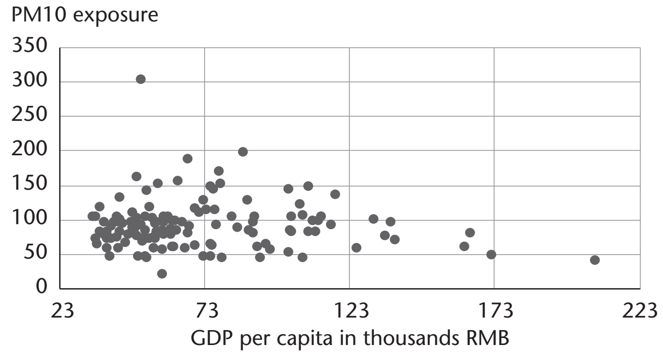

Figure 3.6 Annual mean PM210 exposure and GDP per capita in Chinese cities, 2014

Source: Compiled from Yale University (2016e).

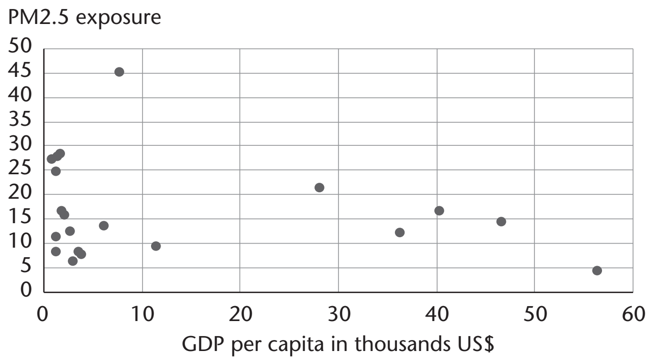

Figure 3.7 Annual mean PM2.5 Exposure and GDP per capita in Asian countries/regions, 2000–2014

Source: Compiled from Yale University (2016e).

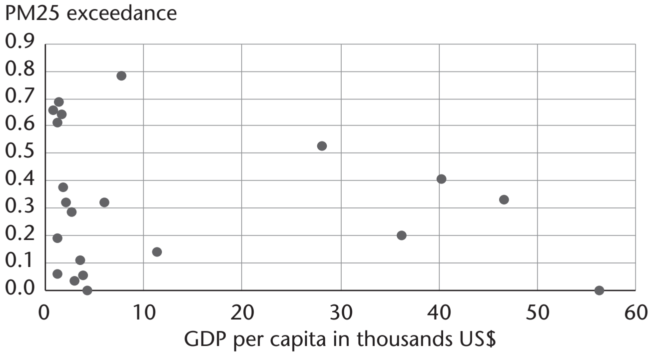

Figure 3.8 Annual mean PM2.5 Exceedance and GDP per capita in Asian countries/regions, 2000–2014

Source: Compiled from Yale University (2016e).

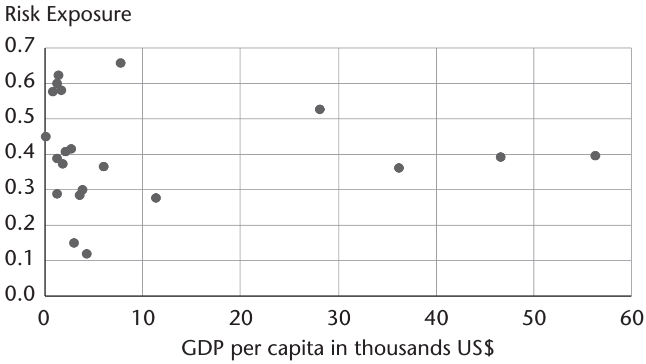

Figure 3.9 Annual mean PM2.5 Health Risk Exposure and GDP per capita in Asian countries/regions, 1990–2013

Source: Compiled from Yale University (2016e).

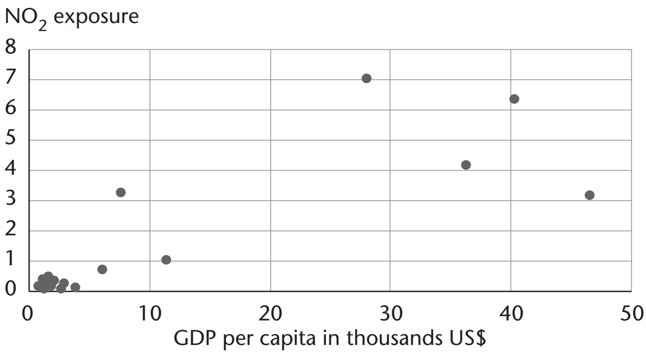

Figure 3.10 Annual mean NO_2 Exposure and GDP per capita in Asian countries/regions, 1997–2011

Source: Compiled from Yale University (2016e).

The literature is inconsistent in the existence of an EKC for air pollution in Asia. As pollution rises to dangerous levels, Asian governments are under pressure to take measures. This is true in almost all countries in Asia, including the most polluted countries such as China, India, Bangladesh, and Pakistan. Some progress has been reported. For example, a newly released UNEP (2015) review found that Beijing was effective in controlling air pollution from coal-fired plants and vehicle emissions. It is possible that major cities have made progress in controlling air pollution in their urban areas. However, it is important to note how this progress has been made in China. To avoid impacting economic growth, city governments often relocate polluting factories from the urban centers to nearby suburban and rural areas or to neighboring cities (Liu 2010, 2012, 2013a, 2013b). Some of these factories have caused severe pollution in their new locations. Some Model Cities have improved their environmental conditions at the expense of surrounding areas. This is supported by Yale's EPI data discussed earlier. Exposure to PM2.5 may have been leveled off or declined in recent years, but an increased proportion of the population has been exposed to PM2.5 pollution (Figures 3.1 and 3.2). Population in rural and suburban areas who benefit the least from polluting industries now suffer more from the pollution (Liu 2012, 2013a, 2013b).

Policy implications

The EKC and the "grow first, clean up later" approach may be extremely harmful to the powerless and poor (Liu 2012, 2013a, 2013b). Developed countries such as Japan took this path and were able to achieve better environmental conditions and some degree of sustainability. At that time, there was insufficient knowledge of the tremendous environmental, social, and economic costs of unsustainable development practices. Today, the importance of sustainability is common knowledge, and science and technology make sustainable practices possible. Political pressure, rather than economic growth, determines when the turning point of the EKC will occur. In an undemocratic political system such as China or some other Asian countries, political pressure may not be large enough to force governments and industries to switch to sustainable practices until much later. The turning point may be delayed if there even is one. Developing countries should avoid this approach and adopt a sustainable path to development and environmental management. Social determinants of health, such as poverty, access, and inequality, are the very determinants that make populations more vulnerable to environmental risk factors and environmental change (Kovats 2012). On the other hand, protecting the environment may bring health benefits and economic benefits from health-care savings, in addition to help with fighting global climate change (WHO 2014a).

Even if an EKC exists in PM2.5 concentration, less-developed countries in Asia are unlikely to be able to afford it, as the turning point requires such high income levels reported by Keene and Deller (2015). Irreversible damage to climactic conditions and human health would be disastrous. As populations in less-developed cities are the most impacted by air pollution (WHO 2016b), the poor in polluted countries suffer the most from air pollution because they do not have the resources to protect themselves and to treat their illnesses. To the millions of people who have died from air pollution, an EKC does not mean anything, even if there is one. Scientific evidence shows that air pollution poses greater risks to human health than we previously realized, particularly in causing strokes and heart diseases (WHO 2014a). In addition, it is projected that the impact on deaths from outdoor air pollution could double by 2050, if the current unsustainable practices continue (Lelieveld et al. 2015). That means the traditional unsustainable approach of "grow first, clean up later" must stop in order to avoid devastating the environment and people's livelihoods.

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