ASSESSMENT OF POPULATION EXPOSURE TO ESTIMATED PM10 CONCENTRATIONS IN MALAYSIA IN 2000, 2008 AND 2013

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ABSTRACT: Epidemiological studies have found that particulate matter less than 10 microns in diameter (PM10) is hazardous to climate and human health. Population-weighted exposure level (PWEL) estimation is fundamental in providing quantitative assessments of areas where the population is vulnerable to the harmful pollutant. This study assesses PWEL of PM10 concentrations in all 16 states of Malaysia for years 2000, 2008 and 2013 using remote sensing and geographic information system (GIS). PM10 concentration estimation method from a local study was applied to validate the estimated PM10 annual mean concentrations with a spatial resolution of 5 kilometers retrieved from satellite data. Population count was obtained from the Gridded Population of the World version 4 (GPWv4) from the Center for International Earth Science Information Network (CIESIN). Estimated PM10 concentrations and gridded population count were then overlaid to generate PWEL of PM10. PWEL of PM10 for each state in Malaysia for the three years were then calculated to study the PWEL of PM10 trend. The concentrations of the pollutant were then classified based on the World Health Organization interim target (WHO IT) guideline. Increasing PWEL of PM10 were seen in 9 states over the 13-year period. Over those years, Putrajaya and Penang had the most increasing trend of PWEL of PM10 with an increment of 119% and 95% respectively. Putrajaya also had the highest recorded PWEL of PM10 (72 µg/m3) in 2013, exceeding the WHO IT class 1 guideline (70 µg/m3). Results based on human exposure analysis show the vulnerability was more towards urban and industrialized states. These results can be used as a decision-making tool and reference for health risk assessment on the population, areas, and sources that need more attention to curb air pollution.

1. INTRODUCTION

Inhalable particulate matters (PM) of an aerodynamic diameter less than or equal to 10 µm has been recognized as one of the most substantial environmental concerns proved to be hazardous to human health. Particulates are therefore selected by the World Health Organization (WHO) in their air quality guideline (AQG) as indicators in evaluation of air pollution and its health effects (WHO, 2005). Many epidemiological studies have assessed the health impacts caused by PM in various extents of time. However, due to limited number of air pollution monitoring stations, air pollution exposure assessment studies are limited in developing countries like Malaysia. Evaluation of population exposure directly using ambient air concentrations should be done with cautious, as studies have reported poor correlations between ambient PM concentrations and human exposure to the particles (Adgate *et al.*, 2002)(Lai *et al.*, 2004). Few studies have also observed that the distribution of atmospheric pollutants varies spatially and temporally, and the actual human exposure levels differ from the mean value(Zhu *et al.*, 2002)(Ito, Xue and Thurston, 2004). Conventional assessments of human exposure disregard the uneven spatial distribution of the pollution and population, which may lead to inconsistent evaluations on the actual human exposure levels. The population weighted exposure levels estimated in this study could provide a basis for more precise targeted intervention policies.

2. MATERIALS AND METHODS

2.1 Site description

Malaysia is a federation consisting of thirteen states and three federal territories (Government of Malaysia, 2009)(Statoids, 2010). Eleven states and two federal territories are located on the Malay Peninsula; two states and one federal territory are located on the island of Borneo. The federal territories will further be mentioned as states in this study for simplicity. This study groups the sixteen states into five regions with regards to their locations; the Central region, Northern region, Southern region, East Coast region and East of Malaysia.

Putrajaya was declared Malaysia's third Federal Territory in 2001 (Statoids, 2010). Before 2001, Putrajaya was a territory entirely enclaved within Sepang, a district in the state of Selangor (John, 2004). Thus, the PM10 and population count for Putrajaya for year 2000 in this study was based on the data within its geographical coordinates.

2.2 PM10 data collection

This study used satellite data for PM10 estimation. Aerosol product of MODIS was downloaded from the National Aeronautics and Space Administration's (NASA) Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC) website. The aerosol products for MOD04, MOD07 and MOD021 were downloaded for year 2000, 2008 and 2013. Using Environment for Visualizing Images (ENVI) software, data on Aerosol Optical Depths (AOD), surface temperature (ST), atmospheric stability (KI) and relative humidity (RH) yielded from the aerosol products were then projected to the WGS84 coordinate system. The annual average concentration of PM10 estimations were then calculated from the projected outputs in Geographic Information System (GIS) software using Artificial Neural Network (ANN) formula from a local study (Kamarul Zaman *et al*., 2017) as follows:

$$PM_{10} = 72.599 + (39.399*H1) + (-31.944*H2) + (-30.735*H3) \quad (1)$$

Where *H* are hidden layers, and:

$$H1 = \mathrm{TANH}(0.5*((-67.612) + (7.216*AOD) + (-0.243*ST) + (0.214*KI) + (0.058*RH))) \quad (2)$$

$$H2 = \mathrm{TANH}(0.5*((-76.084) + (3.464*AOD) + (-0.319*ST) + (0.254*KI) + (0.057*RH))) \quad (3)$$

$$H3 = \mathrm{TANH}(0.5*((-32.739) + (-0.667*AOD) + (-0.169*ST) + (0.114*KI) + (0.075*RH))) \quad (4)$$

2.3 Population data collection

Population count was downloaded from the Gridded Population of the World version 4 (GPWv4) (Center for International Earth Science Information Network, 2018). Earlier versions of GPW have been widely used in global population studies (Prasannavenkatesh *et al.*, 2015)(Sun *et al.*, 2013). The GPWv4 population count consists of estimates of human population in 5-year intervals starting from year 2000. Gridded population estimates for year 2008 and 2013 in this study were calculated as follows:

$$P_x = P_y e^{rt} \quad (5)$$

Where P_x is the population estimate in the target year *x*, P_y is the base population, *r* is the annualized growth rate and *t* is the number of years between population counts.

2.4 Population-weighted exposure level to PM10 calculation based on AQGs

Using kriging method, annual PM10 concentration estimations for each state were spatially interpolated at a resolution of 0.05° x 0.05°, approximately 5km x 5km. Gridded population data with spatial resolution of 0.05° x 0.05° matching that of PM10 concentration data were retrieved from the GPWv4 and converted to points to extract the values. PM10 concentration and population layers were overlaid using the GIS spatial information analysis function to obtain mean annual PM10 concentration for Malaysia and its states. Based on the exposure equation, we calculated the population-weighted exposure level (PWEL) of PM10 for each state. The PWEL of the given grid i is calculated as follows:

$$PWEL = \Sigma(P_i \times C_i) / \Sigma P_i \quad (6)$$

Where P_i is the population in grid *i*, and C_i is its mean annual PM10 concentration. The PWEL of PM10 of each state were then classified according to the World Health Organization interim target (WHO IT) for PM10 mean annual concentrations.

3. RESULTS AND DISCUSSION

3.1 Regional characteristics and population exposure to PM10 in states of Malaysia

Table 1 represents the total geographical area, demographic details and the population densities of each state over the study period. Population density was highest in the central region and lower in the east coast region and east of Malaysia. Urbanization has undoubtedly contributed to the metropolitan states; Kuala Lumpur, Selangor, Putrajaya and Pulau Pinang, having the highest population density in Malaysia.

Table 1. Demography and area proportion of Malaysia and its states.

Region	State	Area ratio (%)	2000		2008		2013	
			Population Ratio (%)	Population density (persons/km^2)	Population Ratio (%)	Population density (persons/km^2)	Population Ratio (%)	Population density (persons/km^2)
Central region	Selangor	2.40	22.73	658	23.85	823	24.54	949
	Kuala Lumpur	0.07	5.68	5375	5.65	6376	5.61	7095
	Putrajaya	0.01	0.20	911	0.23	1266	0.25	1562
Northern region	Pulau Pinang	0.31	5.05	1124	5.07	1345	5.06	1505
	Perak	6.36	8.75	95	8.29	108	7.98	116
	Kedah	2.85	6.59	161	6.41	186	6.30	205
	Perlis	0.24	1.06	306	0.77	263	0.73	281
Southern region	Johor	5.80	11.09	133	11.12	159	11.16	179
	Negeri Sembilan	2.01	3.68	127	3.56	146	3.50	161
	Melaka	0.52	2.44	328	2.54	406	2.59	463
East coast region	Pahang	10.88	5.30	34	5.05	38	4.88	42
	Terengganu	3.93	3.72	66	3.50	74	3.35	79
	Kelantan	4.57	5.38	82	5.02	91	4.80	97
East Malaysia	Sarawak	37.65	8.69	16	8.35	18	8.14	20
	Sabah	22.36	9.40	29	10.37	38	10.96	46
	Labuan	0.03	0.24	613	0.24	702	0.15	493
Malaysia		100.0	100.0	10058	100.0	12040	100.0	13293

Table 2. Mean Annual PM_{10} concentration and population-weighted exposure levels of PM_{10} in Malaysia and its states (unit μg/m³)

Region	State	2000		2008		2013	
		Mean PM_{10} concentration	PWEL of PM_{10}	Mean PM_{10} concentration	PWEL of PM_{10}	Mean PM_{10} concentration	PWEL of PM_{10}
Central region	Selangor	53	51	41	44	51	55
	Kuala Lumpur	65	67	56	49	70	57
	Putrajaya	67	33	54	58	73	72
Northern region	Pulau Pinang	42	20	50	36	55	38
	Perak	48	44	36	32	46	40
	Kedah	47	37	46	39	53	50
	Perlis	43	29	48	46	67	54
Southern region	Johor	47	39	36	32	53	41
	Negeri Sembilan	47	44	37	38	54	40
	Melaka	49	38	40	27	51	36
East coast region	Pahang	42	38	32	30	50	46
	Terengganu	43	37	35	36	49	49
	Kelantan	42	41	33	36	58	40
East Malaysia	Sarawak	41	36	31	30	39	34
	Sabah	42	35	33	29	40	34
	Labuan	42	41	43	43	45	46
Malaysia		47	39	41	38	53	46

Table 2 shows the comparison of PM10 concentrations in Malaysia and its states before and after weighting. It shows that population exposure to PM10 calculated with population-weighting was overall lower than the mean concentration in most states indicating that most people were exposed to a lower PM10 concentration than the actual mean. This indicates that PWEL of PM10 can be influenced by geographic and demographic factors.

Results have also revealed that between 2000 and 2013, Putrajaya and Pulau Pinang were the top two states with the highest increase in PWEL of PM10 of 119% and 95% respectively. Which corresponds with both states having the largest number of establishments from 2010 to 2015 of 23% and 9% compounded annual growth rate respectively (Department of Statistics Malaysia, 2016).

3.2 Population-weighted exposure based on AQGs

Table 3 shows WHO's recommended AQG and interim targets (IT) for annual mean of PM10 (WHO, 2005). ITs are proposed by the WHO as a guideline with the intention to reduce mortality risks from exposures to air pollutants by promoting progressive pollutant emission control. The detailed quantities and proportions of population and the area meeting the different annual standards of PM10 before and after weighting are summarized in Table 4 and 5. Differences in area and population exposure to different vulnerability levels can be observed between the ambient and population-weighted PM10 concentration.

Using GIS software, the PWEL of PM10 distribution map according to WHO AQGs and ITs during the study period was created (Figure 1 – 3). Over the study period, 65.48% to 73.47% of the Malaysia population were living in areas with PM10 levels ranging from 31 µg/m³ to 50 µg/m³, level 3 exposure as according to the WHO standards. However, population exposure to the pollutant became worst in 2013, where the whole country was seen to be in above level 2 exposure and Putrajaya recorded PWEL of PM10 of 72 µg/m³) in 2013, exceeding the WHO IT class 1 guideline, putting the Putrajaya population vulnerable to level 5 exposure.

Table 3. WHO air quality guidelines and interim targets for annual mean PM_{10} concentrations.

Annual Mean level	PM10 (µg/m³)	Basis for the selected level
Interim target-1 (IT-1)	70	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	50	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to the IT-1 level.
Interim target-3 (IT-3)	30	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the IT-2 level.
Air quality guideline (AQG)	20	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5.

Table 4. The Malaysia population and area distributions in different PM10 concentration levels according to WHO guideline and interim targets for annual mean PM10 concentrations.

Level	Pollution ranges	2000		2008		2013	
		Area Ratio (%)	Population Ratio (%)	Area Ratio (%)	Population Ratio (%)	Area Ratio (%)	Population Ratio (%)
1	PM10 ≤ 20	0.00	0.00	0.00	0.00	0.00	0.00
2	20 < PM10 ≤ 30	0.00	0.00	0.00	0.00	0.00	0.00
3	30 < PM10 ≤ 50	97.51	71.39	99.60	89.05	70.33	30.59
4	50 < PM10 ≤ 70	2.49	28.61	0.40	10.95	29.66	69.16
5	PM10 > 70	0.00	0.00	0.00	0.00	0.01	0.25

Table 5. The Malaysia population and area distributions in different PWEL of PM10 concentration levels according to WHO guideline and interim targets for annual mean PM10 concentrations.

Level	Pollution ranges	2000		2008		2013	
		Area Ratio (%)	Population Ratio (%)	Area Ratio (%)	Population Ratio (%)	Area Ratio (%)	Population Ratio (%)
1	PWEL ≤ 20	0.31	5.05	0.00	0.00	0.00	0.00
2	20 < PWEL ≤ 30	0.24	1.06	71.41	26.30	0.00	0.00
3	30 < PWEL ≤ 50	96.97	65.48	28.58	73.47	97.27	68.87
4	50 < PWEL ≤ 70	2.47	28.41	0.01	0.23	2.71	30.88
5	PWEL > 70	0.00	0.00	0.00	0.00	0.01	0.25

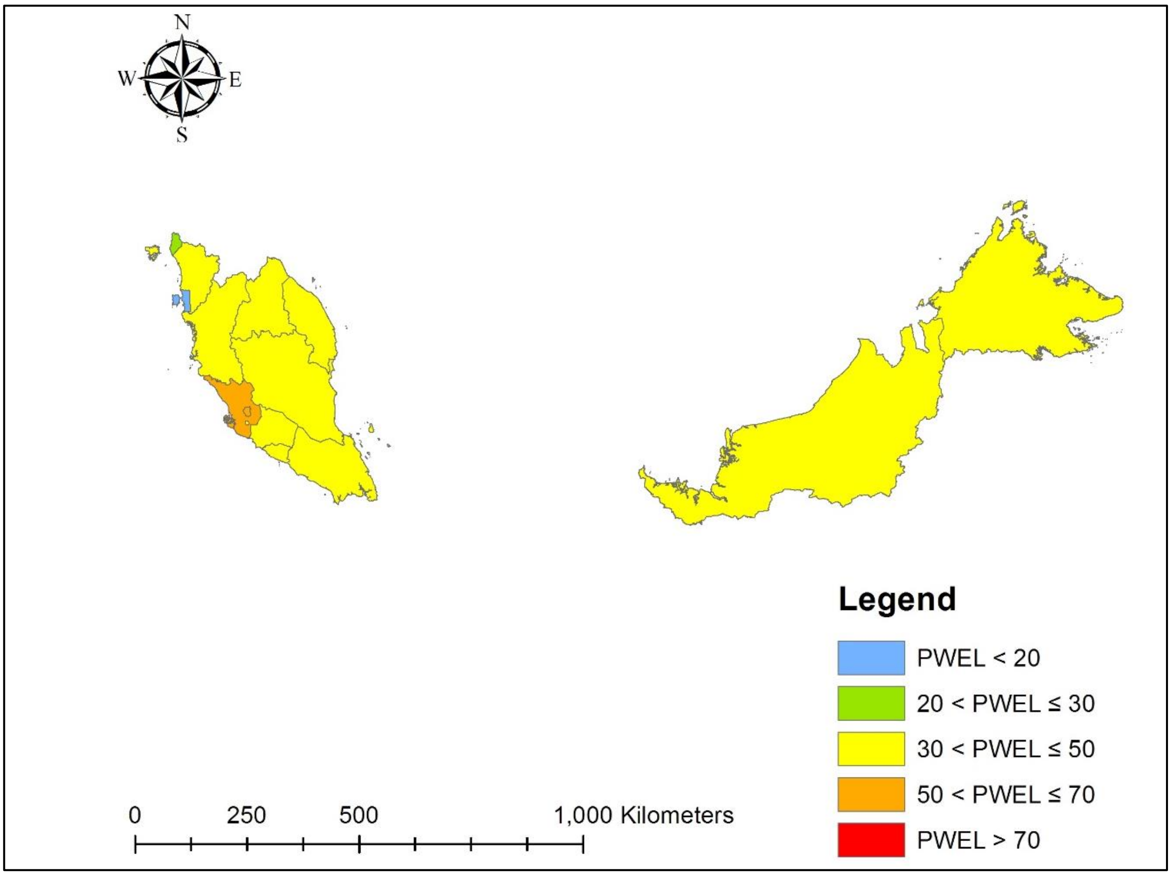

Figure 1. The area distributions of Malaysia in different PWEL of PM10 concentration levels according to WHO guideline and interim targets for annual mean PM10 concentrations in 2000.

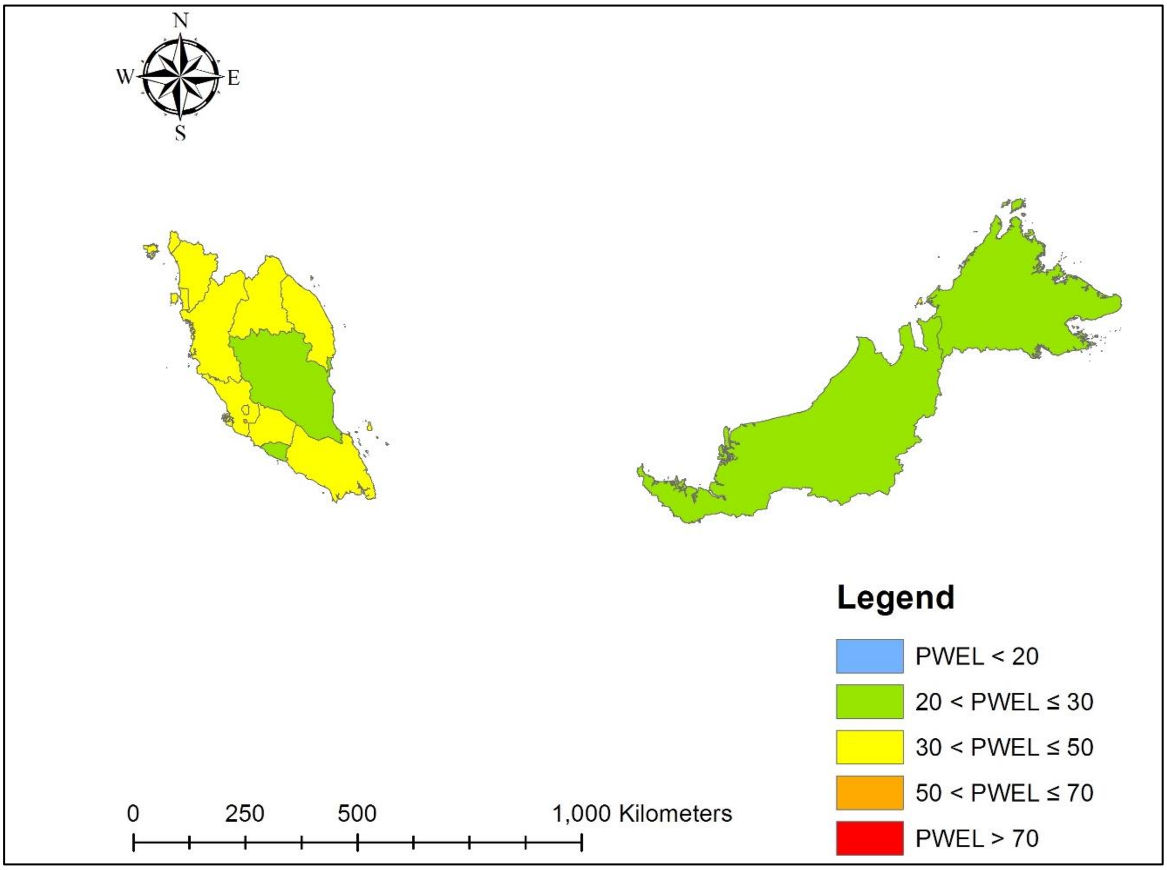

Figure 2. The area distributions of Malaysia in different PWEL of PM10 concentration levels according to WHO guideline and interim targets for annual mean PM10 concentrations in 2008.

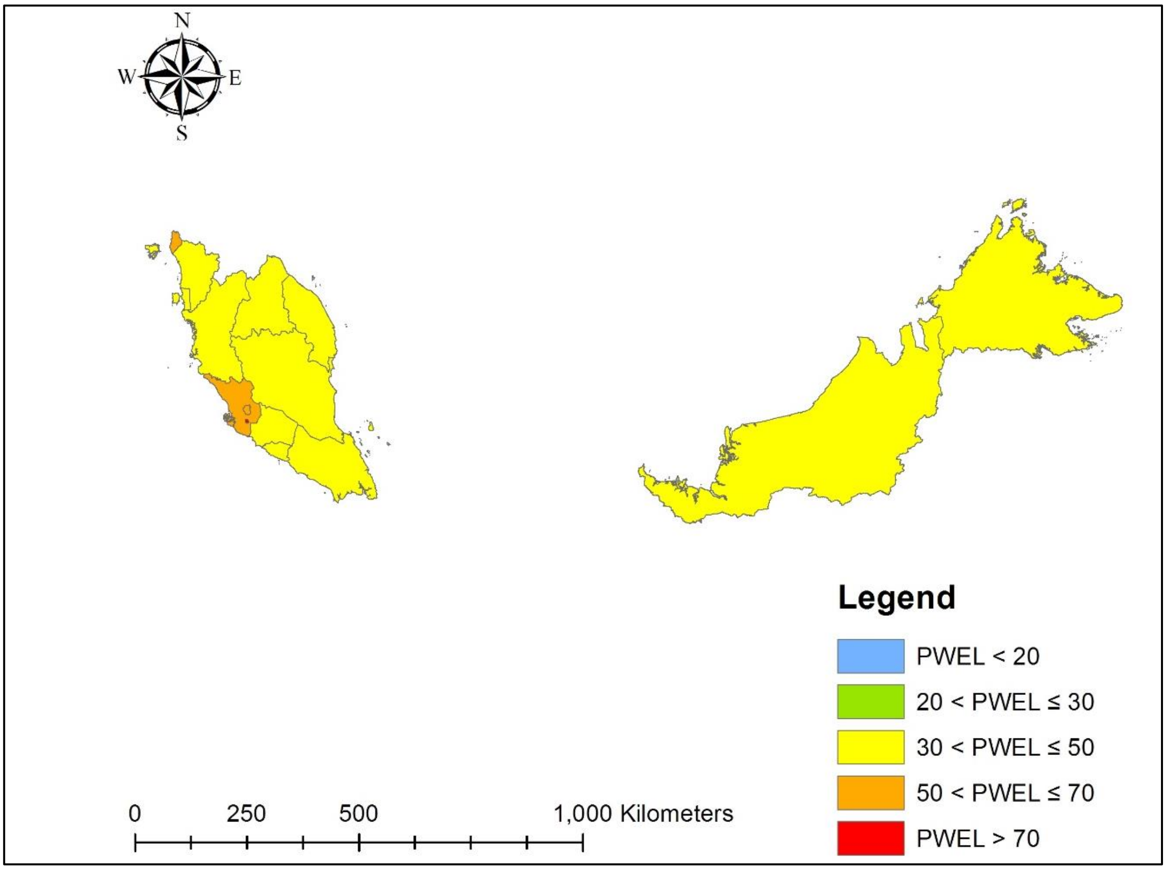

Figure 1. The area distributions of Malaysia in different PWEL of PM10 concentration levels according to WHO guideline and interim targets for annual mean PM10 concentrations in 2013.

4. CONCLUSION

This research has shown that due to the spatial distributions of PM10 and the non-uniform human population in Malaysia, different population numbers were exposed to different concentration ranges. Results also revealed that the annual population exposure to PM10 in Malaysia for 2000, 2008 and 2013 generally have not achieved the WHO guideline. It is evident that the population are exposed to worsening levels of PM10 concentration. Over time, more areas are experiencing worsening levels of PM10 concentration as more areas are being developed. This encourages the population to migrate to these urbanized areas due to better facilities and job opportunities. Eventually, more people would be living in higher exposure levels of air pollution. Exposure reduction interventions should be enhanced to achieve the lowest possible pollutant concentrations in the context of public health policies.

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