The burden of air pollution in Thailand 2021

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Key Findings

- **What was air quality like in Thailand in 2021?**
  The measured 2021 annual mean $PM_{2.5}$ concentrations for each province included in this report range from 12.7 to 31.7 µg/m^3. Across the whole population included in the study the weighted annual mean $PM_{2.5}$ exposure was 21.3 µg/m^3, more than four times higher than the Air Quality Guideline recommended by the World Health Organization (WHO).
- **What were the health impacts?**
  It is estimated that long-term exposure to $PM_{2.5}$ in the provinces included in this study contributed to 29,000 premature deaths during 2021.
  Had $PM_{2.5}$ concentrations in these locations met the WHO guideline, the number of premature deaths attributable to $PM_{2.5}$ pollution could have been reduced by 77%, saving an estimated 22,000 lives each year.
- **How do deaths from air pollution compare to fatalities from other causes?**
  Across the provinces included in this report, there were an estimated 29,000 premature deaths attributable to $PM_{2.5}$ exposure in 2021. Per capita, this fatality rate is greater than the combined rate of fatalities from road accidents, drug use and homicide in Thailand.
- **What time of year has the worst air pollution?**
  Exposure to $PM_{2.5}$ during the months of January, February and March accounted for almost 50% of the exposure during 2021. During these three months weather conditions and agricultural burning compound the air quality problems that are created by road traffic, industry and other uses of fossil fuels.
- **How can air quality in Thailand be improved?**
  A commitment from the Thai government to follow the WHO's new Air Quality Guidelines with time bound strategies and plans. It should include eliminating $PM_{2.5}$ sources by phasing-out coal and fossil fuels, transitioning to renewable energy, tackling transboundary maize-haze, applying sustainable urban design and setting the $PM_{2.5}$ national standard to meet the WHO guidelines to protect citizen's lives.

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Introduction

"The global burden of disease associated with air pollution exposure exacts a massive toll on human health worldwide: exposure to air pollution is estimated to cause millions of deaths and lost years of healthy life annually. The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diet and tobacco smoking, and air pollution is now recognized as the single biggest environmental threat to human health."

The World Health Organization (WHO, 2021)

Not only are the consequences of exposure to air pollution tragic for the individuals affected, but they also have wider implications for our society and the economy. It leads to shortened lives, increased medical costs, and reduced productivity through lost working days (HRAPIE, 2013).

Computer modelling has projected that the annual population-weighted exposure to $PM_{2.5}$ across all urban areas in Thailand is 27 $\mu g/m^3$ (WHO, 2016, in Annex 1) and that in 2012, 17% of all the deaths of Thai people from across the country aged 14 and older could be attributed to long term exposure to $PM_{2.5}$ from fossil-fuel combustion (Vohra et al., 2021).

This report uses ground level monitoring data to estimate the number of premature deaths that can be attributed to fine particulate matter air pollution ($PM_{2.5}$, see Box 1). Long-term exposure to $PM_{2.5}$ pollution is considered in Bangkok and 30 out of the 76 Thai provinces. Only those provinces for which $PM_{2.5}$ data are available are included, these areas are home to about half of Thailand's population. Comparison is also made against four major city regions, New York, Delhi, Kuala Lumpur and Seoul.

The air pollution problems facing society today are closely linked to the climate crisis through a common cause, the combustion of fossil fuels and unsustainable agricultural practices. The Intergovernmental Panel on Climate Change (IPCC) reported in 2022 that a substantial reduction in fossil fuel use is required to reduce emissions of greenhouse gases and air pollutants, and that because the cost of low-emission energy has dramatically reduced it can now be more costly to maintain emission-intensive infrastructure than to transition to renewable energy (IPCC, 2022).

Box 1: What is $PM_{2.5}$?

Particulate matter (PM) is pollution in the form of small liquid or solid particles suspended in the atmosphere. PM pollution is described according to the size of the particles, rather than the chemicals within them.

$PM_{2.5}$ refers to any particle that is less than 2.5 micrometres across; it is sometimes known as *'fine particulate matter'* or *'fine suspended particles'* (FSP). $PM_{2.5}$ particles are small enough to penetrate deep into the lungs to the gas-exchange region (Morakinyo et al., 2016).

The World Health Organization (WHO) publishes guidelines for air quality which are designed to protect public health. The WHO Air Quality Guidelines are determined through detailed reviews of the latest scientific research and apply to concentrations of different air pollutants over differing averaging periods. In many countries, including Thailand, there are also national air pollution standards. However, in Thailand, the national standards are substantially weaker than the WHO's Air Quality Guidelines (Table 1). To encourage progress in locations where existing standards and pollution concentrations significantly exceed the WHO guideline concentrations, interim targets are also suggested by the WHO. The WHO guideline, selected interim targets and the current national standards for annual mean concentrations of $PM_{2.5}$ are shown in Table 1.

Table 1: The World Health Organization Air Quality Guidelines and Thai national air quality standards for annual average concentrations of $PM_{2.5}$.

	Annual mean $PM_{2.5}$ concentration ($\mu g/m^3$)
National Standard in Thailand	25
WHO Interim Target 2 (IT-2)	25
WHO Interim Target 3 (IT-3)	15
WHO Guideline	5

Source: WHO (2021), Kutlar Joss et al. (2017)

Methods

The number of premature deaths that can be attributed to long-term $PM_{2.5}$ exposure are estimated using ground-level air quality measurements for 2021. The measured annual average concentrations of $PM_{2.5}$ are combined with population for each location and country-wide public health data for Thailand. Scientific risk models are then applied to the data in order to quantitatively estimate the health costs of exposure to $PM_{2.5}$ air pollution in each location. In addition to the actually measured $PM_{2.5}$ exposure, a further three scenarios are examined by the analysis in order to estimate the potential health benefit from improving air quality in Thailand (Table 2).

This report only assesses premature mortality. Only those causes of mortality where robustly quantifiable relationships with air pollution have been established in the literature and where epidemiological data are available for Thailand in the Global Burden of Disease (GBD, 2019) catalogue are included (Table 3). Many more health impacts can be attributed to $PM_{2.5}$ exposure, including non-lethal health outcomes such as low birth weight (Dadvand et al., 2013), preterm birth (Trasande et al., 2016), increase in asthma symptoms (HRAPIE, 2013), increase in hospital admissions and emergency room visits due to asthma (Zheng et al., 2015), and mental health issues (Braithwaite et al., 2019).

Table 2: Scenarios

Scenario	**Description**	**Description**
A	2021 Actual	Assessment of premature deaths attributable to $PM_{2.5}$ exposure **for measured annual mean $PM_{2.5}$ concentrations during 2021**
B	National Standard in Thailand (= WHO IT-2)	Assessment of premature deaths attributable to annual mean $PM_{2.5}$ exposure **had WHO IT-2 been achieved in all places where it was not actually achieved**
C	WHO IT-3	Assessment of premature deaths attributable to annual mean $PM_{2.5}$ exposure **had WHO IT-3 been achieved in all places where it was not actually achieved**
D	WHO Guideline	Assessment of premature deaths attributable to annual mean $PM_{2.5}$ exposure **had the WHO Guideline been achieved in all places.**

Ground-level Air Quality Measurements

The analysis uses measured annual and monthly mean $PM_{2.5}$ observations in Thailand aggregated by province from IQAir and published in their *2021 World Air Quality Report* (IQAir, 2021). The data include that from governmental and regulatory monitoring stations, as well as non-regulatory stations operated by individuals, educational institutions, and non-profit organisations.

Monitors operated by non-governmental organisations and individuals underwent quality checks by IQAir before being included in the *2021 World Air Quality Report* (IQAir, 2021). Photo submissions are used to verify that the sensor is in a suitable, sheltered, outdoor location. IQAir continuously checks that the carbon-dioxide (CO_2) concentration, humidity and temperature readings reflect outdoor conditions during operation. The data are also screened for outlying data points when compared with neighbouring monitoring stations during IQAir's quality assurance checks (IQAir, private communication).

The measurements from individual monitoring stations are grouped by the province in which they are located. IQAir uses the average of each individual station within the same province to determine an annual mean $PM_{2.5}$ concentration for that province. This provides an approximation of the province-wide annual average $PM_{2.5}$ concentration. The distribution of monitors within each province is not considered and if the monitors are preferentially located in heavily or lightly polluted areas the $PM_{2.5}$ concentration calculated may over or under-estimate the true province wide average. However, since monitors are usually located where people live, we assume that the data provide a good approximation for the population's average exposure.

Real-world air pollution datasets are rarely complete. Outages during maintenance and technical faults result in missing data. To ensure that systematic bias resulting from diurnal or seasonal patterns in $PM_{2.5}$ concentration are minimised, data are only included where observations are available for at least 90% of the hours and on at least 90% of days during 2021.

Health Impact Assessment

Premature deaths resulting from exposure to $PM_{2.5}$ are assessed for the four pollution scenarios listed in Table 2. The following causes of mortality are included: premature mortality from all causes and a breakdown by a selection of specific causes, namely stroke and other cerebrovascular diseases (CeVD), diabetes, ischaemic heart disease (IHD), lung cancer (LC), lower respiratory infections (LRI) and chronic obstructive pulmonary disease (COPD).

Incidence rates for deaths by these causes for Thailand, and – for comparison – for New York state, India, Malaysia and South Korea are taken from the Global Burden of Disease catalogue (GBD, 2019).

Risk functions are used to estimate the incidence of premature mortality attributable to $PM_{2.5}$ pollution at a given concentration. Table 4 shows the relative risk for a 10 μg/m^3 increase in annual mean $PM_{2.5}$ concentration. Risk ratios and incidence rates are combined with the population number of each location as recorded by Thailand's National Statistical Office (NSO, 2022) (see Table 5) to convert death rates to absolute death numbers per province.

Population data for each of the four reference cities is adopted from IQAir (2021).

The actual incidence N of each cause of mortality is estimated for each province using the location's population P and national (or state, for New York) incidence rate n_a.

$$N = P \times n_a$$

The relative risk RR of each cause of mortality for a given increase in annual mean $PM_{2.5}$ concentration is estimated using the risk ratio r_0 (relative risk at 10 μg/m^3 increase) and pollutant concentration, c.

$$RR = r_0^{(c/c_0)},$$

with c_0=10 μg/m^3. The incidence of each cause of mortality for a hypothetical scenario with completely clean air is estimated by,

$$N_0 = \frac{N}{RR}$$

The incidence attributable to the measured annual mean $PM_{2.5}$ concentration can therefore be calculated by subtracting the actual incidence and that which is estimated to occur in the clean air scenario. To estimate the incidence for each subsequent scenario where different $PM_{2.5}$ concentrations c_S are achieved, N_s, the incidence in clean air is related to the relative risk by

$$N_s = N_0 \times \left(r_0^{(c_S/c_0)} - 1\right).$$

In places where a scenario's goal was already achieved in 2021, the actually measured annual mean $PM_{2.5}$ concentration is used (i. e. the air quality was not worsened in any of the scenarios).

Uncertainty

The premature mortality figures presented here represent useful estimates of the real-world effect of air pollution based on currently available scientific knowledge and data. Like all research, the data and method used contain uncertainty. This uncertainty relates to the precision and representativeness of pollution measurement data, demographic and epidemiological data. Scientific understanding of the relation between exposure to air pollution and the associated risks for health is an active area of research. The estimates account only for long-term exposure to $PM_{2.5}$ and not for other air pollutants which are also known to have negative health impacts.

Pollutants such as nitrogen dioxide (NO_2), ozone (O_3) and sulphur-dioxide (SO_2) typically have poorer data availability than $PM_{2.5}$. Furthermore, health impacts from reactive species such as NO_2 are not included in our results because these pollutants tend to have high spatial variability and thus the data from point measurements are less representative for the whole province.

The uncertainty associated with the risk ratios and background incidence rates are presented in Tables 3 and 4.

Table 3. Relative uncertainties in the background incidence rates **(1/100,000/year)** used in the health impact assessment.

Location	Risk factor	Incidence per 100,000 (95%-confidence interval)					
		central	low	high	downward uncertainty	upward uncertainty	Name of *cause* in GBD (2019)
Thailand	**all causes**	**710**	**555**	**896**	**-22%**	**26%**	***All causes***
	CeVD	73	55	94	-24%	28%	*Stroke*
	Diabetes	28	21	36	-25%	30%	*Diabetes mellitus*
	IHD	74	56	94	-24%	27%	*Ischemic heart disease*
	LC	33	25	43	-24%	30%	*Tracheal, bronchus, and lung cancer*

	LRI	44	27	58	-38%	31%	*Lower respiratory infections*
	COPD	27	21	36	-25%	31%	*Chronic obstructive pulmonary disease*
New York City	**all causes**	**844**	**731**	**963**	**-13%**	**14%**	***All causes***
Delhi		**675**	**606**	**750**	**-10%**	**11%**	
Seoul		**597**	**576**	**618**	**-3%**	**4%**	
Kuala Lumpur		**562**	**463**	**679**	**-18%**	**21%**	

Table 4. Risk ratios (RRs) and their relative uncertainty used for the health impact assessment, for a 10 μg/m^3 change in annual average pollutant concentration. Uncertainties are not given for *RR* itself but for *RR* - 1, since that is the deviation from zero-effect (*RR* = 1).

	Value central	**Value low**	**Value high**	**Source**	**Downward uncertainty**	**Upward uncertainty**
premature death (all causes)	**1.062**	1.040	1.083	HRAPIE 2013	-35%	34%
premature death (CeVD)	**1.110**	1.050	1.170	Pope 2015	-55%	55%
premature death (diabetes)	**1.130**	1.020	1.260	Pope 2015	-85%	100%
premature death (IHD)	**1.140**	1.100	1.180	Pope 2015	-29%	29%
premature death (LC)	**1.142**	1.057	1.234	Krewski 2009	-60%	65%
premature death (LRI)	**1.120**	1.030	1.300	Mehta 2011	-75%	150%
premature death (COPD)	**1.128**	1.077	1.182	Krewski 2009	-40%	42%

Results

The measured 2021 annual mean $PM_{2.5}$ concentrations for each province included in this report range from 12.7 to 31.7 μg/m³ (Table 5, Figure 1). The population-weighted annual mean $PM_{2.5}$ concentration was 21.3 μg/m³.[1] While this concentration is within the National Standard in Thailand (25 μg/m³), it is more than four times higher than the health based Air Quality Guideline recommended by the WHO (Table 1). Exposure to $PM_{2.5}$ air pollution at these concentrations increases the risk of premature death by about 14% (9%-19%[2]; HRAPIE, 2013).

Important sources of particulate matter include vehicles and biomass burning (Kanchanasuta et al. 2020). Seasonal weather conditions such as rainfall can remove these pollutants, but other conditions including atmospheric temperature inversions can prevent pollutant dispersion (Fold et al 2020). These seasonal effects mean that in the provinces studied here, 49% of the total 2021 exposure to $PM_{2.5}$ happened in just three months from January to March (Figure 2). During these months the combined effect of weather conditions and seasonal pollutant emissions such as agricultural burning compound the air pollution problem that exists year-round as a result of pollution sources like road traffic. Despite the strong seasonal trend, measured monthly mean $PM_{2.5}$ concentrations in Bangkok remain above the WHO annual mean guideline of 5 μg/m³ in every month of the year.

It is estimated that long-term exposure to $PM_{2.5}$ in the provinces included in this study contributed to 29,000 premature deaths during 2021 (Table 5). In Bangkok where the measured annual mean $PM_{2.5}$ concentration was 20 μg/m³, the risk of premature death from exposure to this pollutant was estimated to be 13% higher than would be the case with clean air. The increased risk corresponds to an estimated 4,400 additional deaths during 2021. Risks and premature deaths for the other provinces included in the study are provided in Table 5.

[1] IQAir (2022) reports a population-weighted annual mean of 20.2 μg/m³ for Thailand. The difference arises from different population numbers used in the weighting. This report uses population numbers for Thailand from the Thailand Statistical Office (NSO, 2022).

[2] 95%-confidence interval

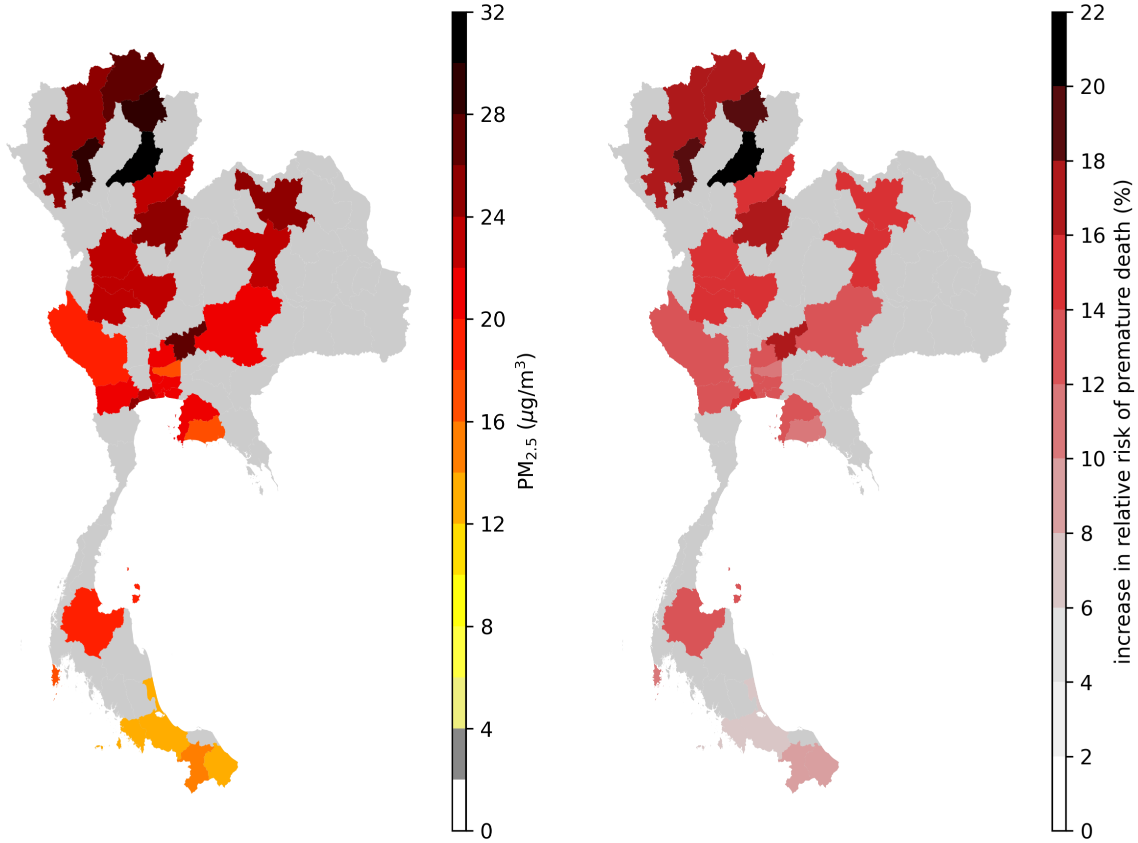

Figure 1: *Left:* Annual mean $PM_{2.5}$ concentrations during 2021 per province. *Right:* Increase in relative risk of premature death attributable to annual mean $PM_{2.5}$ concentrations during 2021 per province. Provinces not included in the study due to insufficient data are shaded grey.

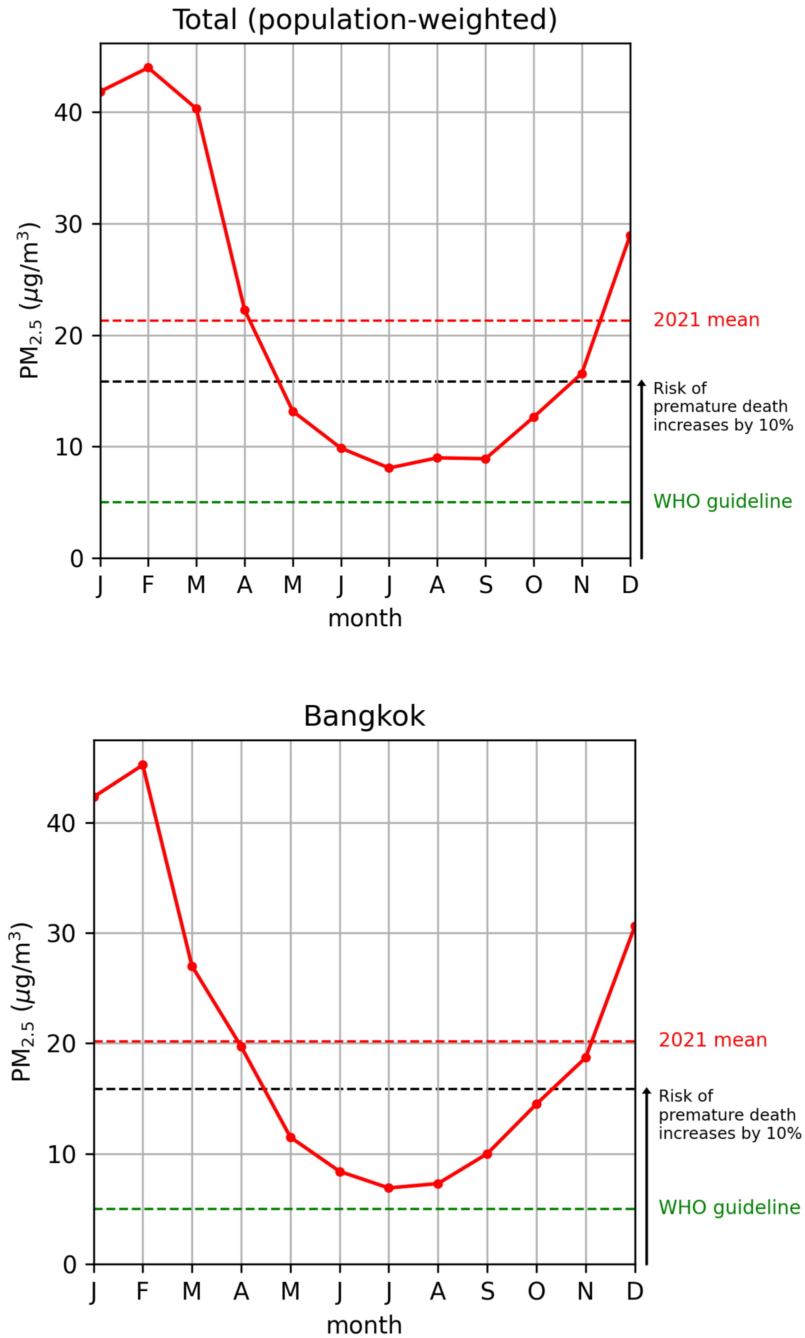

Figure 2: Monthly mean $PM_{2.5}$ concentrations during 2021 in the country-wide average (top) and in Bangkok (bottom).

Table 5: Measured annual mean $PM_{2.5}$ concentrations during 2021, associated increase in risk of premature death and number of annual premature deaths attributable to this amount of $PM_{2.5}$ pollution. Totals for $PM_{2.5}$ concentration and increased risk of premature death are population-weighted.

Province	Population	$PM_{2.5}$ (µg/m^3)	Increased risk of premature death	Premature deaths due to $PM_{2.5}$
Total	*34,047,570*	***21.6***	*+14%*	***28,831***
Bangkok	5,527,994	**20.0**	+13%	**4,446**
Nakhon Ratchasima	2,634,154	**20.3**	+13%	**2,149**
Khon Kaen	1,790,863	**22.6**	+15%	**1,615**
Chiang Mai	1,789,385	**24.9**	+16%	**1,766**
Chon Buri	1,583,672	**21.7**	+14%	**1,375**
Udon Thani	1,566,510	**24.1**	+16%	**1,500**
Songkhla	1,431,536	**12.7**	+8%	**747**
Samut Prakan	1,356,449	**21.1**	+14%	**1,147**
Chiang Rai	1,298,425	**27.1**	+18%	**1,386**
Nonthaburi	1,288,637	**20.8**	+13%	**1,075**
Pathum Thani	1,190,060	**17.5**	+11%	**844**
Surat Thani	1,072,464	**18.9**	+12%	**818**
Nakhon Sawan	1,035,028	**22.9**	+15%	**945**
Kanchanaburi	894,054	**19.4**	+12%	**699**
Ratchaburi	868,281	**21.6**	+14%	**751**
Phitsanulok	847,384	**25.0**	+16%	**840**
Phra Nakhon Si Ayutthaya	820,512	**21.7**	+14%	**712**
Narathiwat	809,660	**13.7**	+9%	**454**
Rayong	751,343	**17.4**	+11%	**530**
Kamphaeng Phet	712,143	**22.0**	+14%	**626**
Saraburi	643,963	**26.1**	+17%	**664**
Samut Sakhon	586,789	**23.3**	+15%	**545**
Yala	542,314	**14.0**	+9%	**311**
Phayao	464,505	**28.9**	+19%	**526**
Uttaradit	446,148	**23.9**	+15%	**424**
Phrae	434,580	**31.7**	+21%	**535**
Phuket	418,785	**17.4**	+11%	**295**
Lamphun	401,139	**28.0**	+18%	**441**
Uthai Thani	325,116	**23.9**	+15%	**309**
Satun	324,835	**12.7**	+8%	**170**
Samut Songkhram	190,842	**24.4**	+16%	**185**

Due to its large population, the estimated premature deaths are most numerous in Bangkok (Figure 3). However, when adjusting for population, the premature death rate which can be attributed to long-term exposure to $PM_{2.5}$ is greatest in Phrae where the annual mean $PM_{2.5}$ concentration is the highest of all provinces included. At 31.7 μg/m^3, the annual mean in Phrae is more than 6 times the WHO guideline and significantly breaches the National Standard in Thailand (Figure 4).

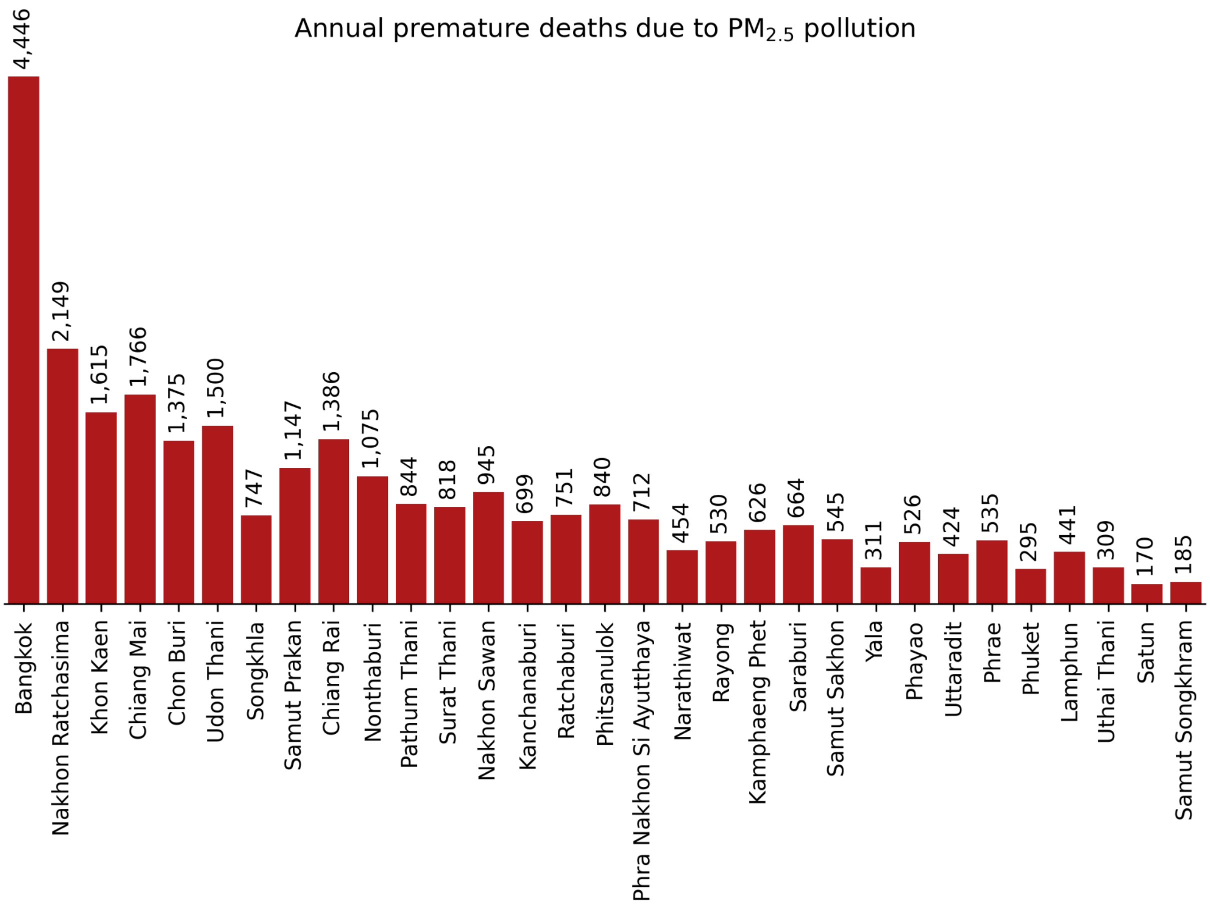

Figure 3: Number of premature deaths that can be attributed to long-term exposure to $PM_{2.5}$ during 2021.

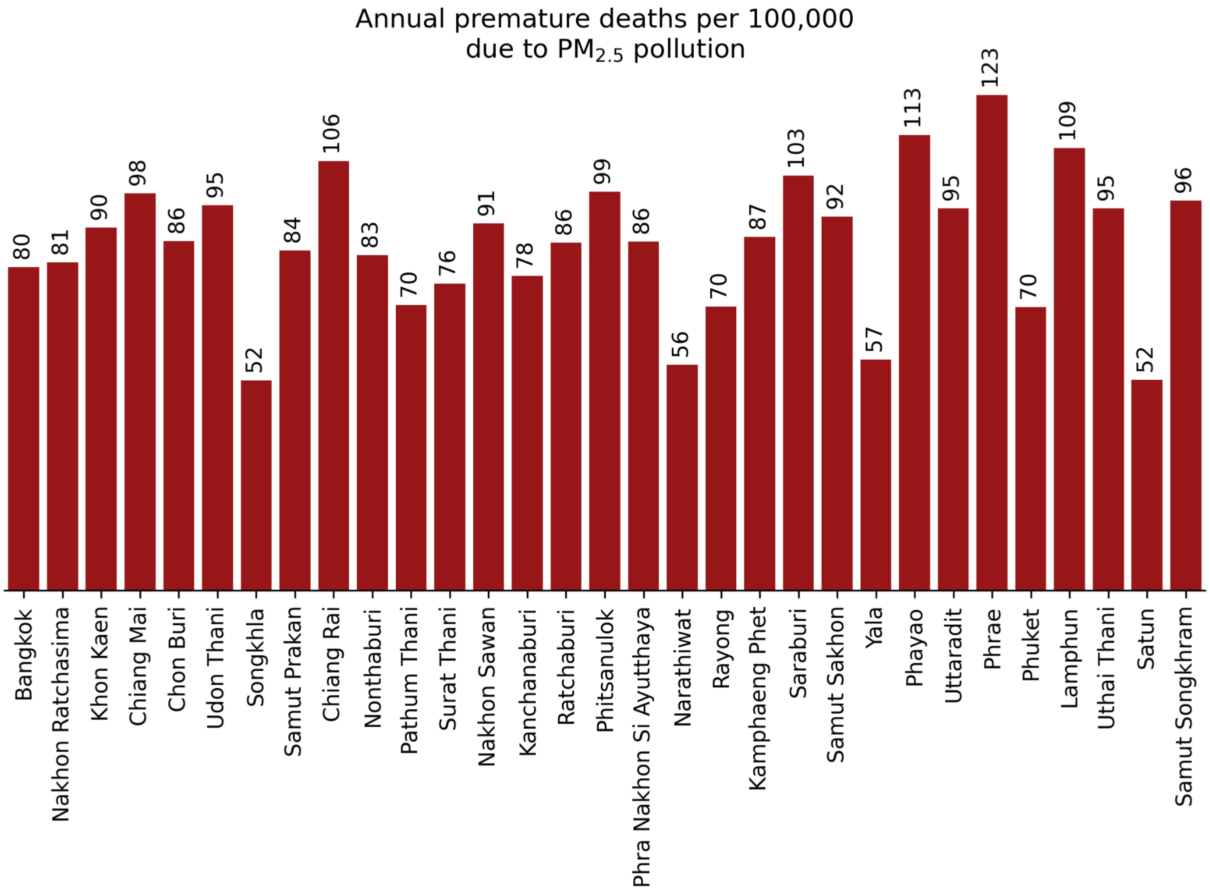

Figure 4: Premature death rate per 100,000 people that can be attributed to long-term exposure to $PM_{2.5}$ during 2021.

We estimate that 12% of all premature deaths that occured in 2021 in the provinces studied can be attributed to exposure to $PM_{2.5}$ pollution. In particular, 20% of premature deaths from stroke and other cerebrovascular diseases, 23% of premature deaths from diabetes, 24% of premature deaths from both ischaemic heart disease or lung cancer, 21% of premature deaths from lower respiratory infections and 22% of premature deaths from COPD in the provinces studied are attributable to $PM_{2.5}$ air pollution (Table 6).

In 2021 all but five of the 36 provinces studied complied with the WHO Interim Target 2 and Thai national target which both limit annual $PM_{2.5}$ pollution to 25 $\mu g/m^3$. If all 36 provinces had complied, around 400 of the 29,000 $PM_{2.5}$-related premature deaths would have been avoided (Table 6, Scenario B). Had each location complied with WHO Interim Target 3, around 9,000 of the 29,000 $PM_{2.5}$-related premature deaths would have been avoided (Table 6, Scenario C).

The Thai national target of 25 µg/m^3 is 5 times as high as the WHO's Air Quality Guideline for annual mean $PM_{2.5}$ concentration. All of the provinces studied failed to meet the WHO guideline in 2021. If all these provinces were to comply with the WHO guideline, this would reduce the number of premature deaths attributable to $PM_{2.5}$ pollution to about 6,000 per year, avoiding 77% of the premature deaths and thus saving 22,000 lives in these provinces each year (Table 6, Scenario D). This is roughly the annual number of road traffic fatalities in all of Thailand (WHO, 2018). As the provinces studied in the report cover only about half the population of Thailand (34 million), someone living in the regions of Thailand included in this study is more than twice as likely to die from exposure to $PM_{2.5}$ pollution as from a road accident (Table 7, Figure 5). In fact, the risk of dying from $PM_{2.5}$ air pollution is currently even substantially higher in Thailand than the risks of dying from a road accident, drug use or intentional homicide combined.

Table 6: Results of the Health Impact and Cost Assessment for 2021

	Scenario A	**Scenario B**	**Scenario C**	**Scenario D**
	Actual	WHO 2021 IT-2	WHO 2021 IT-3	WHO guideline
premature death (all causes)	**28,831**	**28,436**	**19,849**	**6,497**
premature death (CeVD)	4,896	4,827	3,326	1,065
premature death (diabetes)	2,159	2,128	1,459	463
premature death (IHD)	6,046	5,958	4,074	1,287
premature death (LC)	2,739	2,700	1,845	582
premature death (LRI)	3,204	3,158	2,171	692
premature death (COPD)	2,088	2,058	1,411	448

Table 7. Various causes of premature deaths in Thailand.

		Exposed population (millions)	Value	Rate per 100,000	Source
Exposure to $PM_{2.5}$ pollution	Scenario A – actual	34.0	28,831	**85**	This report
	Scenario B – current national standard	34.0	28,436	**84**	
	Scenario C – WHO IT-3	34.0	19,849	**58**	
	WHO guideline	34.0	6,497	**19**	
Road accidents		66.2	22,491	**34**	WHO (2018)
Drug use		66.2	10,674	**16**	GBD (2019)
Intentional homicide		66.2	1,800	**3**	World Bank (2022)
Sum of road accidents, drug use, homicide				*53*	

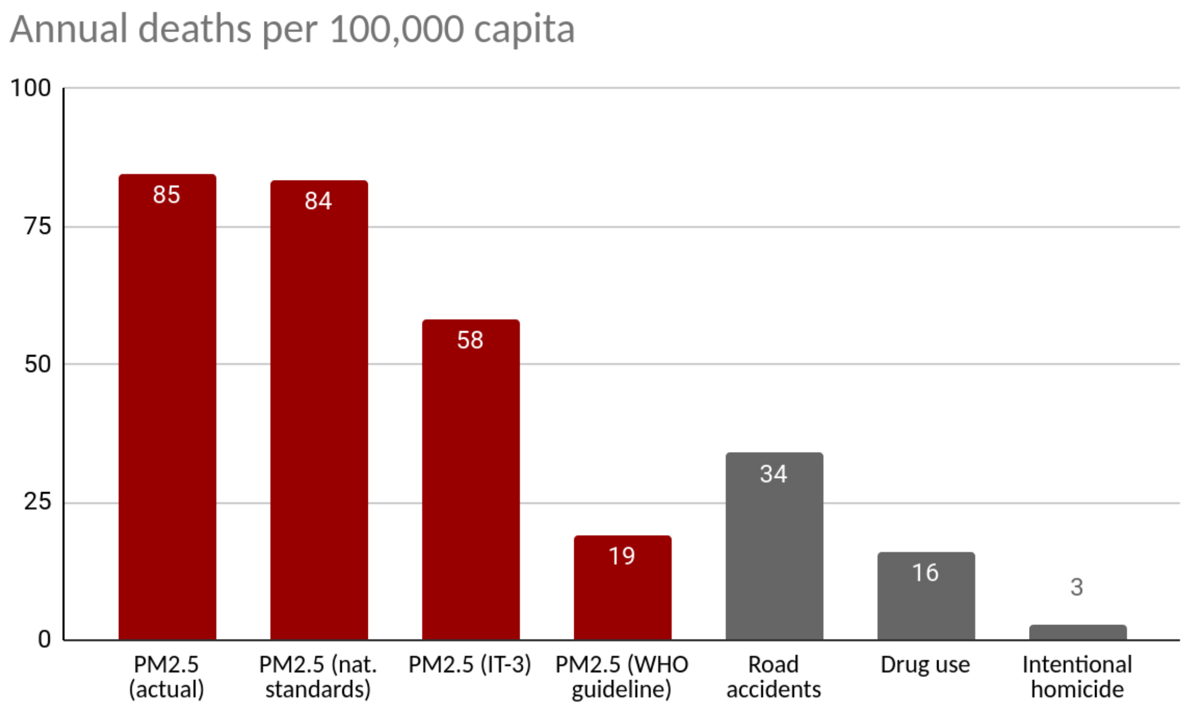

Figure 5: Comparison of deaths per 100,000 people that can be attributed to long-term exposure to $PM_{2.5}$ during 2021 for Scenarios A, B, C and D (red) and other causes (grey).

A comparison of Bangkok with the four major city regions of New York, Delhi, Seoul and Kuala Lumpur reveals that the risk of premature deaths resulting from long-term $PM_{2.5}$ exposure is similar in Seoul and Kuala Lumpur (Table 8). In New York, where $PM_{2.5}$ concentrations in 2021 were approximately 50% of those measured in Bangkok, the risk is also estimated to be approximately 50% lower. In contrast, Delhi, which experiences a much higher $PM_{2.5}$ burden, has a much higher risk of premature deaths resulting from long-term $PM_{2.5}$ exposure.

Table 8. Comparison with World Cities

City region	Population	$PM_{2.5}$ (µg/m^3)	Increased risk of premature death	Premature deaths due to $PM_{2.5}$
Bangkok	5,527,994	20.0	+13%	4,446
New York City	18,713,220	10.0	+6%	9,217
Delhi	29,617,000	96.4	+79%	88,010
Seoul	21,794,000	19.7	+13%	14,533
Kuala Lumpur	8,285,000	18.6	+12%	4,928

Conclusion

There has never been more evidence that air pollution affects health, and we know that these effects can occur even at low concentrations (WHO, 2021). The findings of this study demonstrate that action is urgently needed to address the problem of $PM_{2.5}$ pollution in Thailand to protect the health of the Thai population.

This year, the IPCC found with high confidence that measures that reduce greenhouse gas and air pollutant emissions, including demand reduction and low emission transport modes, have the potential to deliver both air quality improvements and health benefits whilst also contributing to the mitigation of climate change (IPCC, 2022).

Efforts to improve air quality have a track record of delivering benefits to our health, environment and economy (US EPA, 2011). The health burden felt today demands a focus on direct reduction of pollutant emissions at source. Addressing the sources of greenhouse gas emissions can achieve improvements to air quality within years (IPCC, 2021), while sustainable urban design can be effective in protecting populations against climate change and air pollution (IPCC, 2022).

The Thai government should commit to follow the WHO's new Air Quality Guidelines with time-bounded strategies and plans. These plans should include eliminating $PM_{2.5}$ sources by phasing-out coal and fossil fuels, transitioning to renewable energy, tackling transboundary maize-haze, applying sustainable urban design and setting the $PM_{2.5}$ national standard to meet the WHO guidelines to protect citizen's lives.

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