



Mortality and Economic Costs of Ambient Air Pollution in Six Major Cities of Bangladesh

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ABSTRACT

Ambient air pollution remains a leading environmental risk factor for premature mortality and economic loss, particularly in rapidly urbanizing low- and middle-income countries such as Bangladesh, where empirical city-level evidence remains limited. This study aimed to quantify the long-term mortality burden (all-cause and cause-specific cardiovascular, respiratory, and lung cancer mortality) and associated economic costs attributable to ambient PM_{2.5} in six major cities of Bangladesh between 2013 and 2021. The annual concentrations of ambient PM_{2.5} from Continuous Air Monitoring Stations (CAMS) of six selected cities (Dhaka, Chattogram, Rajshahi, Sylhet, Khulna, and Barisal) of Bangladesh were used for exposure assessment in this study. The present study applied literature-derived Concentration- exposure- response functions to estimate the all-cause and cause-specific mortality burden linked to PM_{2.5} among those living in the cities during study period. A valuation of the economic loss attributed to premature mortality was made utilizing the Value of Statistical Life methods. In 2021, the average mortality burden of PM_{2.5} in the six cities per 100,000 population was 260 (95% CI: 142-370) premature deaths from all causes, 112 (95% CI: 61-160) from cardiovascular diseases, 25 (95% CI: 13-38) from respiratory diseases, and 3 (95% CI: 1-4) from lung cancer. The economic costs for all-cause mortality related to PM_{2.5} across six cities were estimated to be \$23 billion USD (\$19.3-\$26.7) in 2021. These findings highlight the substantial public health and economic burden of ambient air pollution in urban areas and underscore the urgent need for strengthened air quality management and evidence-based policy interventions.

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INTRODUCTION

Ambient air pollution remains a major global environmental health risk, responsible for approximately 4.2 million deaths worldwide, with the majority of these cases occurring in Low and Middle Income Countries (LMICs) (WHO, 2022). Rapid urbanization, industrial

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expansion, fossil fuel dependence, and changing household energy patterns have contributed to rising ambient pollution levels in these settings (Abbas et al., 2021; Mannucci & Franchini, 2017; Mashaal et al., 2025; Rasel et al., 2024). Of these pollutants, $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter of $\leq 2.5 \mu m$) has been frequently linked with higher all-cause mortality as well as cause-specific mortality from major non-communicable diseases (Basith et al., 2022). Epidemiological research has shown that prolonged exposure to ambient $PM_{2.5}$ substantially increases the risk of cardiovascular mortality, respiratory mortality, and lung cancer mortality (Lee et al., 2014). Each $10 \mu g/m^3$ increase in $PM_{2.5}$ was associated with an increased hazard risk of 29% in all-cause mortality (Guo et al., 2022). Additionally, $PM_{2.5}$ is linked to acute and chronic cardio-respiratory illnesses, resulting in hospital and emergency room visits (Nasari et al., 2016), carrying notable economic consequences (Bayat et al., 2019).

Bangladesh has been affected by high levels of ambient air pollution for many years. In 2021, Bangladesh was the most polluted nation in the world, and its average ambient $PM_{2.5}$ concentration ($76.9 \mu g/m^3$) was 15 times more than World Health Organization (WHO) air quality guidelines (IQAir, 2022). Dhaka, the capital of Bangladesh is highly polluted city in Bangladesh with more than 23 million people. This city recorded an annual average $PM_{2.5}$ concentration of $82 \mu g/m^3$ in 2019, originating from diverse pollution sources such as urbanization, industrialization, and increased motorization, with emissions from transport and brick industries adversely affecting the city's air quality and human health (Abdelzaher et al., 2024; Ashraful Haque et al., 2017; Razib et al., 2020). Beyond Dhaka, the other major cities of Bangladesh are also facing significant negative impacts regarding air pollution (Bari et al., 2016; Sattar et al., 2005). Consequently, the health burden and economic loss pose adverse effects in these major cities of Bangladesh (Khandker et al., 2022).

Recent studies have quantified the health and economic impacts of $PM_{2.5}$ exposure in urban and national contexts, employing integrated exposure–response models and valuation techniques (Aktar & Shimada, 2014; Khandker et al., 2022). For instance, studies in rapidly urbanizing regions have demonstrated substantial mortality and GDP losses attributable to long-term $PM_{2.5}$ exposure, highlighting the importance of city-level assessments for targeted policy interventions (Etchie et al., 2017; Hadei et al., 2020; K. J. Maji, Ye, et al., 2018). However, existing studies in Bangladesh remain largely limited to single-city analyses, short time frames, or focus exclusively on health outcomes without economic valuation. Moreover, comparative assessments across multiple major cities using harmonized exposure and mortality data are notably absent. To date, no study has systematically estimated both the mortality burden and associated economic costs of long-term $PM_{2.5}$ exposure across multiple major cities in Bangladesh over an extended period. This study addresses this critical gap by providing a comprehensive, city-level assessment of $PM_{2.5}$ -attributable mortality and economic losses across six major urban cities in Bangladesh from 2013 to 2021. This study not only provides critical insights for Bangladesh but also contributes valuable evidence to the international discourse on the mortality and economic burdens of $PM_{2.5}$, particularly in rapidly urbanizing LMICs. Moreover, these estimates can help inform policymakers to understand the scale of the mortality-related impacts from ambient air pollution.

Research Objectives

1. To estimate the long-term all-cause and cause-specific (cardiovascular, respiratory, and lung cancer) premature mortality attributable to ambient $PM_{2.5}$ exposure in six major cities of Bangladesh from 2013 to 2021
2. To quantify the economic costs associated with $PM_{2.5}$ -attributable premature mortality using the Value of Statistical Life (VSL) approach.

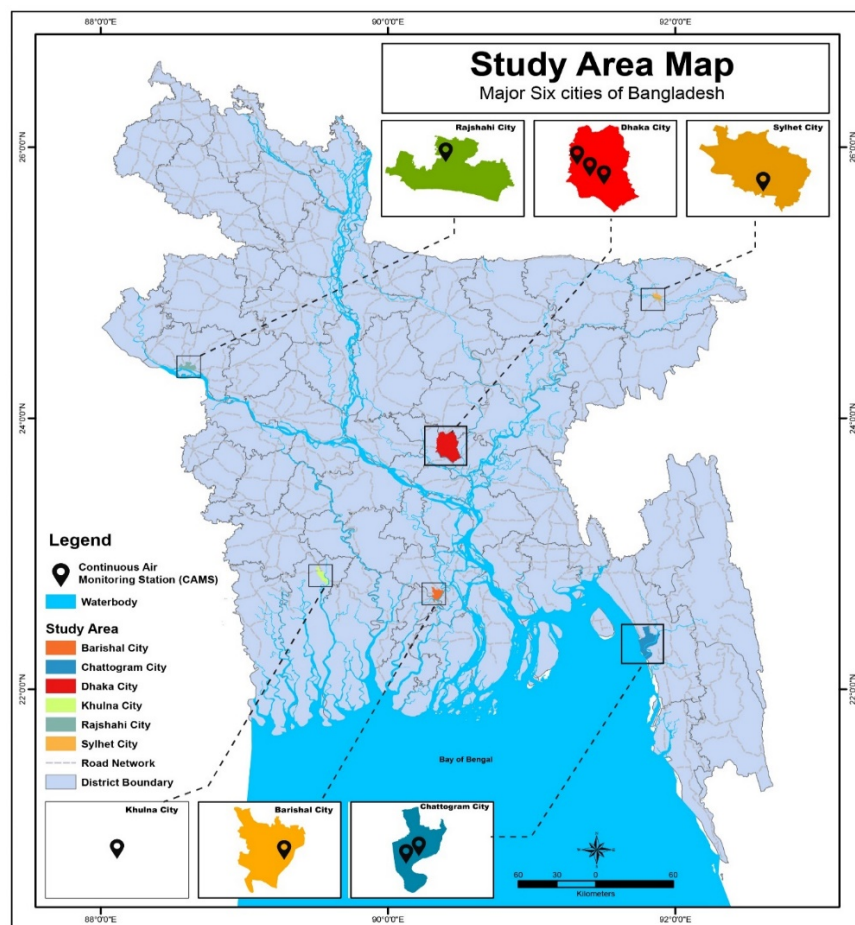


Fig. 1. Study area map

MATERIALS & METHODS

Study area

The six largest cities in Bangladesh were the focus of this investigation. These cities are Dhaka, Chattogram, Rajshahi, Sylhet, Khulna, and Barisal (**Fig. 1**).

Health impact estimation of ambient air pollution

Four categories of input data are employed to estimate the excess number of deaths that are attributable to ambient $PM_{2.5}$: 1) annual concentration of ambient $PM_{2.5}$ as a proxy for exposure, 2) health outcomes including mortality rate of major diseases, 3) estimate of the exposed population, 4) the concentration-response function linking $PM_{2.5}$ and health outcomes.

Measurement of $PM_{2.5}$: $PM_{2.5}$ data were obtained from the Department of Environment (DoE) of Bangladesh. The DoE, as the national regulatory authority, operates a total of nine Continuous Air Monitoring Stations (CAMS) that monitor ambient $PM_{2.5}$ concentrations across the six major cities selected for the present study [*Three CAMSs are in Dhaka city, two CAMSs in Chattogram city and one CAMS in other cities*]. Using a limited number of CAMS to estimate exposure may not fully capture fine-scale spatial variability within cities. However, in our observational air pollution data analysis from 2013 to 2021 in Dhaka city, we found limited intra-city variability of $PM_{2.5}$, with inter-station differences of approximately 5–15 $\mu\text{g}/\text{m}^3$ across the three CAMS locations. The DoE supplied the hourly concentration data of $PM_{2.5}$ at each

CAMS from January 1, 2013 to December 31, 2021. This study converted hourly air quality data into annual average data for each selected city for the related health impact assessment in order to conduct statistical analysis.

Demographic and health data

This study obtained the baseline death rate of specific diseases (all-cause mortality, cardiovascular mortality, respiratory mortality, and lung-cancer mortality) in all cities per 100,000 population from the Global Burden of Diseases (GBD) database (IHME, 2021). Multiple previous studies have utilized this dataset to quantify mortality attributable to air pollution (Cohen et al., 2017; Pandey et al., 2021). All-cause mortality for all age groups was included in this study.

Population data

The primary population data incorporated in this analysis is the annual resident population at the city level. The MacroTrends database was used to obtain city-specific population estimates, as official census data from the Bangladesh Bureau of Statistics are conducted decennially and were not available for all study years (Macrotrends, 2024).

Concentration-response function (CRFs)

This study estimated the long-term health impacts associated with PM_{2.5} exposure by applying the Relative Risk (RR), which links PM_{2.5} concentration to mortality across six major cities from 2013 to 2021. To calculate the long-term health effects (all-cause mortality, cardiovascular mortality, respiratory mortality, and lung-cancer mortality) caused by PM_{2.5}, this study used the following equation based on previous research (Guan et al., 2021; Hadei et al., 2020).

$$HI = AP * BI * P \quad (1)$$

Where HI is the health impacts of specific diseases, AP is the attributable proportion, BI is the baseline incidence rate for specific diseases per unit population, and P represents the exposed population. Attributable proportion (AP) i.e., the percentage of deaths attributed to PM_{2.5} exposure, was calculated by using following equation (Hadei et al., 2020):

$$AP = RR - 1 / RR \quad (2)$$

This function has mostly been used for the estimation of health impacts in high PM_{2.5} polluted regions. Case-specific RR was calculated through the following equation (K. J. Maji, Ye, et al., 2018).

$$RR = \exp^{[ER*(C_a - C_0)]} \quad (3)$$

Where ER is the exposure-response coefficient, C_a is the annual average ambient PM_{2.5} concentration, and C₀ is the threshold concentration (5µg/m³) according to WHO standard and existing literature (Han et al., 2022; Naimi et al., 2024) . Exposure-response (ER) coefficient can be divided by the following expression (K. J. Maji, Ye, et al., 2018):

$$ER = \ln RR / \Delta x \quad (4)$$

Δx represents increment. We have obtained the RR from a systematic review and meta-analysis to ensure the robustness of the ER value (Chen & Hoek, 2020). Exposure-response coefficients, commonly referred to as Beta coefficients, are used to estimate RR associated with

Table 1. Relative risk (RR) per 10 micrograms per cubic meter increase of PM_{2.5} concentration for long-term mortality effects

Pollutants	Health Outcomes	RR (95% CI)	Reference
PM _{2.5}	All-cause mortality	1.08(1.06-1.09)	(Chen & Hoek, 2020)
	Cardiovascular mortality	1.11(1.09-1.14)	
	Respiratory mortality	1.10(1.03-1.18)	
	Lung cancer	1.12(1.07-1.16)	

specific levels of pollutant exposure. We employed RR as the measure of effect to assess the relationship between health outcomes and a 10 µg/m³ increase in particulate air pollution. RR per 10 µg/m³ increase of PM_{2.5} concentration for long-term mortality effects is presented in **Table 1**. The referenced meta-analysis primarily included studies from North America, Europe, and East Asia, with limited representation from South Asia and other low- and middle-income regions; this should be considered when applying the risk estimates to Bangladesh.

Economic burden calculation

To estimate the mortality cost of particulate air pollution in Bangladesh, the Value of Statistical Life (VSL) from the Organization for Co-operation and Development (OECD) countries is adjusted to derive the VSL for Bangladesh. This adjustment is based on the Purchasing Power Parity (PPP) estimates of Gross Domestic Product (GDP) per capita for both Bangladesh and the OECD countries. The GDP of both Bangladesh and OECD countries was used based on World Bank data (World Bank, 2024). The VSL for Bangladesh is calculated by multiplying the VSL from OECD countries (VSL_{OECD}) by the ratio of GDP per capita in Bangladesh to GDP per capita in the OECD countries, raised to the power of the income elasticity of willingness to pay (WTP), denoted as 'e' (Bayat et al., 2019; Hadei et al., 2020). According to study, the most recent estimate for OECD countries suggests a VSL of USD 3.83 million (at 2011 purchasing power parity (PPP) (Bayat et al., 2019). The formula for this adjustment is as follows:

$$VSL_{Bangladesh} = VSL_{OECD} * \left(\frac{Y_{Bangladesh}}{Y_{OECD}} \right)^e$$

Where VSL_{Bangladesh} is the Value of a Statistical Life in Bangladesh, VSL_{OECD} is the Value of a Statistical Life in OECD countries, Y_{Bangladesh} is the GDP per capita in Bangladesh, Y_{OECD} is the GDP per capita in OECD countries, and e is the income elasticity of willingness to pay (WTP). An income elasticity of 1 was applied in the present study in accordance with existing literature, as Bangladesh is classified as a lower-middle-income country; however, it is acknowledged that the income-VSL relationship may be non-linear across different income levels (Masterman & Kip Viscusi, 2018).

In this study, the VSL for OECD countries in 2021 is estimated to be \$4.50 million. This value is derived by adjusting the 2011 VSL of \$3.83 million to 2021 prices, using an average annual inflation rate from 2011 to 2021 of 1.6% applicable to OECD countries. The adjustment ensures that the VSL reflects the most current economic conditions and is consistent with the inflationary trends observed over the period. The calculation follows a standard inflation adjustment methodology, compounding the annual inflation rate over the 10-year period from 2011 to 2021. Based on these assumptions and data, VSL_{Bangladesh} is estimated to amount to 258,298 USD in 2021. The value of life lost due to the exposure across all selected cities was estimated as:

$$Value\ of\ Life\ Lost = VSL_{Bangladesh} * h * N$$

Where N represents the total number of deaths from all causes that are linked to the exposure across all selected cities. The total cost of deaths caused by PM_{2.5} pollution is calculated by multiplying the number of deaths by the Value of Statistical Life for Bangladesh (VSL_{Bangladesh}).

However, uncertainty in this study was quantified only for the epidemiological component of the analysis using the 95% confidence intervals of the relative risk estimates. Other parameters, including PM_{2.5} exposure concentrations, baseline mortality rates, and VSL were treated as point estimates (i.e., fixed values without associated uncertainty distributions). Formal compound uncertainty propagation across multiple model components was not performed because well-defined uncertainty distributions for all major inputs are not available in the Bangladeshi context. This approach is consistent with common practice in large-scale benefit-transfer and global burden assessments (Anenberg et al., 2010; Robinson et al., 2019).

RESULTS AND DISCUSSION

Ambient air pollution concentrations

The annual average air pollution concentrations in six major cities across Bangladesh, namely Dhaka, Chattogram, Rajshahi, Sylhet, Khulna, and Barisal, from 2013 to 2021 are shown in **Fig. 2**. The average PM_{2.5} concentration varied from 34.7 to 143.7 (µg/m³) between the years 2013 and 2021 in these cities. This indicates that the WHO ambient air quality standard was exceeded by PM_{2.5} at all times. In 2013, Rajshahi recorded mean concentrations of 69.9 µg/m³ for PM_{2.5}. Over the period from 2013 to 2021, there was a 21.7% increase in PM_{2.5}, reaching 85.1 µg/m³ in Rajshahi city. However, the overall highest PM_{2.5} concentration was 83.4 µg/m³ (Dhaka) in 2013. The highest level of PM_{2.5} concentrations between these years was 143.7 µg/m³, faced by Khulna in 2016. A similar finding was also recorded in a Bangladeshi study, revealing that power plant construction, numerous industrial facilities, such as factories, power plants, and manufacturing divisions, biomass burning, and large vehicular emissions are the significant contributors to facing this highest level of pollution in 2016 (Khatun, 2024). In 2021, the city that had the highest PM_{2.5} concentration was Dhaka (88.8 µg/m³). Dhaka has consistently exhibited the highest levels of pollution, with Sylhet as the least polluted. However, the western regions, namely Khulna and Rajshahi, had higher pollution levels compared to their eastern counterparts, Sylhet and Chattogram. This finding revealed that all the major cities in Bangladesh are facing a significant impact of ambient air pollution. Similar findings were found in multiple studies conducted in Bangladesh in different years (Bari et al., 2016; Masum et al., 2020). Factors such as high population density, substantial pollutant emissions, and regional

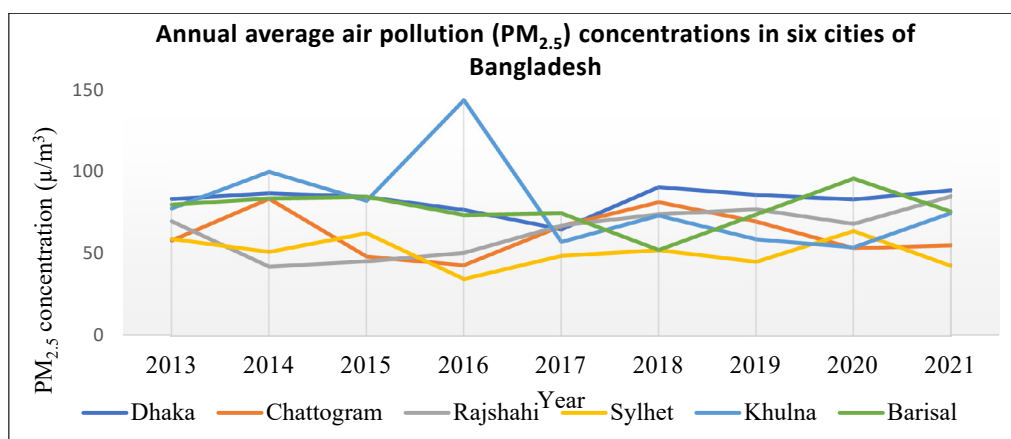


Fig. 2. Annual average air pollution concentrations (PM_{2.5}) in six cities in Bangladesh from 2013 to 2021

Table 2. All-cause mortality for PM_{2.5} per 100000 populations at risk in six selected cities from 2013 to 2021

Air Pollutants	Area	Population								
		2013	2014	2015	2016	2017	2018	2019	2020	2021
PM _{2.5}	Dhaka	236 (213-259)	247 (221-273)	241 (211-272)	226 (194-260)	204 (175-235)	266 (223-308)	257 (215-300)	293 (251-343)	316 (268-370)
	Chattogram	175 (158-192)	240 (214-265)	149 (131-168)	135 (116-156)	210 (179-241)	245 (205-284)	217 (182-254)	202 (173-236)	213 (181-249)
	Rajshahi	205 (185-225)	132 (118-145)	141 (123-159)	157 (135-182)	211 (180-242)	228 (190-263)	236 (198-276)	250 (214-292)	306 (260-358)
	Sylhet	177 (160-195)	158 (141-175)	188 (165-212)	109 (94-125)	158 (135-182)	168 (141-195)	147 (123-172)	236 (202-276)	167 (142-196)
	Khulna	223 (201-245)	274 (245-303)	236 (206-266)	349 (300-402)	183 (157-211)	225 (188-261)	188 (158-220)	204 (174-238)	277 (235-323)
	Barisal	229 (206-251)	240 (215-265)	241 (211-272)	218 (188-252)	229 (196-264)	168 (141-195)	228 (191-267)	326 (279-381)	279 (237-326)

pollutant transport are attributed to this high pollution (Ashraful Haque et al., 2017).

Premature mortality attributed to air pollutant

All-cause mortality: The all-cause premature mortality per 100,000 population, attributed to long-term air pollutants exposure in six major cities is shown in **Table 2**. From 2013 to 2021, the average all-cause mortality for PM_{2.5} was 218 [95% CI: 188-248] per 100,000 population across all the selected cities in Bangladesh. According to the air quality data from DoE, Rajshahi is the second most polluted city in Bangladesh. Over the period from 2013 to 2021, there was a 21.7% increase in PM_{2.5} levels in Rajshahi. Consequently, all-cause mortality also increased by more than 49%. By 2021, the three cities with the highest all-cause premature mortality for PM_{2.5} were Dhaka [316 (95% CI: 268-370)], Rajshahi [306 (95% CI: 260-358)], and Barisal [279 (95% CI: 237-326)] per 100,000 Populations, respectively. This study has seen an increased mortality trend over the years 2013 to 2021 in Dhaka (34%), and Chattogram (22%), Rajshahi (49%), Khulna (24%), and Barisal (22%). On the flip side, the mortality rates were slightly improved for the city of Khulna. This rise and fall in mortality trend were consistent with PM_{2.5} concentration. This study revealed that Bangladesh's six central cities have experienced a significant amount of all-cause mortality from the air pollutant PM_{2.5} over the years. The previous study conducted in Bangladesh among different cities found similar findings (Masum et al., 2020). Increased population exposure with multiple air pollutant sources made this situation worse day by day. The factors such as outdated and unsuitable vehicles, industrial operations, increased brick kilns, small-scale industrial setups, as well as landfill and construction sites contribute substantial amounts of pollutants to the air on a daily basis (Mahmud, 2020). The vast numbers of people from cities are regularly exposed to these pollutants, which contribute to serious health problems and premature mortality (Khandker et al., 2022).

Additionally, temporal trend in PM_{2.5}-attributable all-cause mortality per 100,000 population across six major cities in Bangladesh from 2013 to 2021 are presented in **Fig. 3**. A statistically significant increasing mortality trend attributable to PM_{2.5} was observed in both Dhaka ($y = 8.83x - 17,563$; $p = 0.03$) and Rajshahi ($y = 16.98x - 34,048$; $p < 0.01$), corresponding to annual increases of approximately 8.8 and 17.0 deaths per 100,000 population, respectively. The observed rise in PM_{2.5}-related mortality is likely driven by rapid urbanization, traffic and industrial emissions, construction and road dust, seasonal biomass burning, and transboundary pollutant transport, collectively increasing air pollution exposure and health risks (Masum et al., 2020; Zakir & Khan, 2024).

Cardiovascular mortality and respiratory mortality

Cardiovascular mortality of PM_{2.5} per 100,000 population in the six selected cities from 2013 to 2021 is presented in **Table 3**. These years, the average death rate from cardiovascular diseases for PM_{2.5} was 98 (95% CI: 83-115) per 100,000 population across all the selected

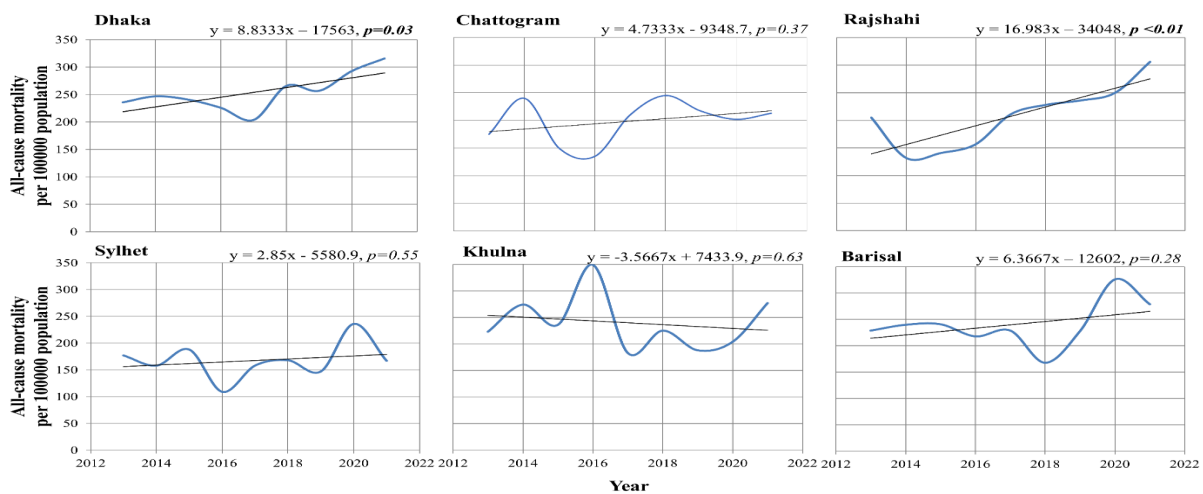


Fig. 3. Temporal trend in $PM_{2.5}$ -attributable all-cause mortality per 100,000 population across six major cities in Bangladesh from 2013 to 2021

Table 3. Cardiovascular mortality for $PM_{2.5}$ per 100000 populations at risk in six selected cities from 2013 to 2021

Air Pollutants	Area	Population								
		2013	2014	2015	2016	2017	2018	2019	2020	2021
$PM_{2.5}$	Dhaka	96	105	106	103	97	127	126	126	134
		(85-108)	(91-118)	(91-121)	(87-119)	(82-114)	(106-150)	(104-149)	(104-151)	(110-160)
	Chattogram	73	102	68	64	100	118	108	89	93
		(65-83)	(89-115)	(59-78)	(54-74)	(83-117)	(98-140)	(90-129)	(74-107)	(77-112)
	Rajshahi	85	59	65	74	100	111	117	109	130
		(75-95)	(51-66)	(56-74)	(62-86)	(84-117)	(92-131)	(96-138)	(90-131)	(107-156)
	Sylhet	74	70	85	52	77	84	76	104	74
		(66-84)	(61-78)	(73-97)	(44-60)	(64-90)	(70-99)	(63-90)	(85-124)	(61-89)
	Khulna	92	115	104	149	88	110	95	90	119
		(81-103)	(100-129)	(89-119)	(126-173)	(74-103)	(91-130)	(78-113)	(74-108)	(97-142)
	Barisal	94	102	106	100	108	84	113	138	119
		(83-105)	(89-115)	(91-121)	(84-116)	(91-127)	(70-99)	(94-135)	(114-165)	(98-144)

cities in Bangladesh. From 2013 to 2021, Khulna recorded the highest $PM_{2.5}$ -related deaths, 149 (95% CI: 126-173) in 2016, while Sylhet recorded the lowest number, with 52 (95% CI: 44-60) deaths, also in 2016. In 2016, the concentration of $PM_{2.5}$ in Khulna city was $143.7 \mu\text{g}/\text{m}^3$, which was the highest among the six selected cities from 2013 to 2021. As a result, the death rate is also highest in Khulna in 2016 for $PM_{2.5}$. In the following 9 years, average mortality from CVD varied from 52 to 149 for $PM_{2.5}$ in all selected cities. There was a steady and sharp increase in mortality, and $PM_{2.5}$ is one of the significant factors behind this increase.

Table 4 provides respiratory mortality rates for $PM_{2.5}$ per 100,000 populations from 2013 to 2021. The average health burden of $PM_{2.5}$ in the six cities was 22 (95% CI: 19-27) from respiratory diseases per 100,000 population in these years. The health burden of respiratory diseases for $PM_{2.5}$ exhibited parallel increases with air quality concentration. The number of respiratory mortalities for $PM_{2.5}$ increased 45%, 30%, and 24% from 2013 to 2021 in Rajshahi, Dhaka, and Chattogram, respectively. Besides this, other cities also follow similar trends. Between these years, mean $PM_{2.5}$ concentration was also increased significantly. The air pollution scenario in Bangladesh is becoming detrimental for citizens. Nearly 85% of the air pollution in the city is generated by surface dust, car emissions, and brick kilns, and the anthropogenic sources are more widely distributed and contribute more (Williams, 2020). As a result, respiratory mortality from ambient air pollution is increasing significantly. Similar findings were also observed in existing literature (S. Maji et al., 2018).

Table 4. Respiratory mortality for PM_{2.5} per 100000 populations at risk in six selected cities from 2013 to 2021

Air Pollutants	Population									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	
PM _{2.5}	Dhaka	23 (20-27)	25 (21-29)	24 (20-29)	23 (19-28)	22 (18-27)	29 (24-36)	28 (23-35)	28 (22-35)	30 (23-38)
	Chattogram	17 (15-20)	24 (21-29)	15 (13-19)	14 (12-17)	23 (19-28)	27 (22-33)	24 (19-30)	20 (16-25)	21 (16-26)
	Rajshahi	20 (17-24)	14 (12-16)	14 (12-18)	17 (14-20)	23 (19-28)	25 (20-31)	26 (21-33)	24 (19-30)	29 (23-37)
	Sylhet	17 (15-21)	16 (14-19)	19 (16-23)	12 (10-14)	17 (14-21)	19 (15-23)	17 (13-21)	23 (18-29)	16 (13-21)
	Khulna	22 (19-26)	27 (23-32)	24 (20-29)	34 (29-42)	20 (16-24)	25 (20-31)	21 (17-26)	20 (16-25)	26 (21-33)
	Barisal	22 (19-26)	24 (21-29)	24 (20-29)	23 (19-27)	24 (20-30)	19 (15-23)	25 (20-32)	31 (24-39)	27 (21-34)

Table 5. Lung cancer mortality of PM_{2.5} in six selected cities from 2013 to 2021

Ambient Air Pollutants	Population									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	
PM _{2.5}	Dhaka	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)	3 (2-4)	3 (2-4)	3 (2-4)	3 (2-4)
	Chattogram	2 (1-2)	2 (2-3)	1 (1-2)	1 (1-2)	2 (2-3)	2 (2-3)	2 (2-3)	2 (1-3)	2 (2-3)
	Rajshahi	2 (1-3)	1 (1-2)	1 (1-2)	2 (1-2)	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)	3 (2-4)
	Sylhet	2 (1-2)	1 (1-2)	2 (1-3)	1 (1-2)	2 (1-2)	2 (1-2)	2 (1-2)	2 (2-3)	2 (1-2)
	Khulna	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-5)	2 (1-3)	2 (2-3)	2 (2-3)	2 (1-3)	3 (2-3)
	Barisal	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)	2 (2-3)	2 (1-2)	2 (2-3)	3 (2-4)	3 (2-4)

Lung cancer mortality

Table 5 provides lung cancer mortality data related to PM_{2.5} in selected major cities from 2013 to 2021, considering per 100,000 populations across six major cities. The average death rate of lung cancer for PM_{2.5} in the six cities was 3 (95% CI: 1-4) per 100,000 population in all selected cities. The lung cancer mortality has gradually increased in Dhaka city over the years. Air pollution in Dhaka is comparatively higher than in the other cities because of rapid urbanization and industrialization. Following this, the death rate in Dhaka city regarding air pollution is also higher (K. J. Maji, Arora, et al., 2018). Similar findings has also been recorded in several studies, reporting that higher air pollution levels negatively affect lung cancer deaths (Khandker et al., 2022; Xue et al., 2022).

Economic loss

Table 6 represents the value of life lost for all-cause mortality. The present study used the VSL method to estimate the economic burden for all-cause premature mortality from 2013 to 2021. In 2021, the economic impact of premature deaths due to PM_{2.5} in Bangladesh amounted to \$23 (\$19.3-\$26.7) billion. This study supports the economic burden due to ambient air pollution among major cities in Bangladesh, which requires collective action towards air pollution for mitigating these burdens. The total value of life lost due to PM_{2.5} increased from USD 5 billion in 2013 to USD 23 billion in 2021. These results indicated that the economic burden of all-cause mortality for ambient air pollution (PM_{2.5}) is substantially increasing over the period from 2013 to 2021. The present findings of this study align with those of other studies evaluating the economic and mortality consequences of air pollution. The mortality burdens associated with air pollution in Jakarta, Indonesia, were estimated to be 10,002 fatalities annually, with

Table 6. Pollutants specific Value of Life Lost for all-cause mortality across all selected six cities combined

Year	All-cause mortality of all selected six cities (Number)	Value of Life Lost (PM _{2.5})	
		(million)	(Billion)
2013	52304 (47115-57351)	\$ 5250 (\$4729-\$5756)	\$ 5 (4.7-\$5.8)
2014	58525 (52319-64687)	\$ 6727 (\$6014-\$7436)	\$ 7 (\$6-\$7.4)
2015	54982 (48126-62126)	\$ 7673 (\$6716-\$8669)	\$ 8 (\$6.7-\$8.7)
2016	53935 (46423-62206)	\$ 10183 (\$8765-\$11745)	\$ 10 (\$8.8-\$11.7)
2017	54317 (46528-62487)	\$ 11039 (\$9456-\$12700)	\$ 11 (\$9.5-\$12.7)
2018	70172 (58719-81193)	\$ 14978 (\$12533-\$17330)	\$ 15 (\$12.5-\$17.3)
2019	68907 (57792-80607)	\$ 16032 (\$13446-\$18754)	\$ 16 (\$13.4-\$18.8)
2020	79472 (68037-92896)	\$ 20429 (\$17490-\$23880)	\$ 20 (\$17.5-\$23.9)
2021	88240 (74843-103186)	\$ 22792 (\$19332-\$26653)	\$ 23 (\$19.3-\$26.7)

an economic cost of USD 2,943.42 million (almost 2.2% of its GDP) for 2019 (Syuhada et al., 2023). Meanwhile, a study from Iran acknowledged that air pollution was considered more than 5.8 billion USD (almost 2.42% of its GDP) per year (Hadei et al., 2020).

Theoretical and conceptual contributions

By integrating long-term, city-level PM_{2.5} exposure, cause-specific mortality, and economic valuation within a unified analytical framework, this study strengthens the theoretical understanding of ambient air pollution by linking epidemiological evidence with economic analysis. Rather than proposing a new exposure–response relationship, it applies established concentration–response functions to estimate premature mortality and related economic losses. The use of consistent functions across six major urban centers enables a comparative multi-city analysis and reveals important spatial differences in health and economic burdens within a single national context. The nine-year longitudinal application further emphasizes air pollution as a chronic and cumulative risk factor. Finally, applying the VSL at the city level strengthens the link between epidemiology and environmental health economics in rapidly urbanizing low- and middle-income countries.

CONCLUSIONS

This study provides the first long-term, multi-city assessment of ambient PM_{2.5}-attributable premature mortality and associated economic losses in Bangladesh, covering six major cities over a nine-year period (2013–2021). The findings revealed that the six major selected cities of Bangladesh are facing significant mortality burdens in terms of all-cause mortality, cardiovascular mortality, respiratory mortality, and lung cancer mortality, and economic costs due to ambient air pollution. This situation is significantly increasing in these cities gradually. By strictly maintaining WHO ambient air quality guidelines, 88240 premature death and \$23 billion USD economic losses in selected cities of Bangladesh could be saved in 2021.

Implications for theory and practices

From a theoretical perspective, the findings support established exposure-response relationship between long-term PM_{2.5} exposure and all-cause as well as cause-specific mortality, while demonstrating their applicability in a real-world, multi-city urban setting in a low- and middle-income country. The substantial inter-city variation in mortality and economic costs observed despite the use of common risk coefficients underscores the need for future theoretical and modelling framework to better incorporate spatial heterogeneity in exposure pattern and population vulnerability. From a practical and policy perspective, the estimated economic losses-reaching approximately USD 23 billion, clearly indicate that ambient air pollution represents

not only a major public health concern but also a significant macroeconomic constraint for Bangladesh. The city-level evidence generated by this study provides a strong empirical basis for cost–benefit analyses of air quality interventions, including stricter vehicle emission standards, regulation of brick kilns, industrial emission controls, and urban dust management.

Key lessons learned

Several key lessons emerge from this study. First, sustained exceedance of WHO air quality guidelines across all six cities indicates that ambient PM_{2.5} exposure remains chronically high, rather than episodic, necessitating long-term structural interventions rather than short-term mitigation measures. Second, the parallel trends observed between PM_{2.5} concentrations and premature mortality across multiple disease categories confirm that reductions in ambient PM_{2.5} could simultaneously lower cardiovascular, respiratory, and lung cancer mortality burdens. Third, the sharp increase in economic losses over time illustrates how delayed action on air pollution compounds future health and economic costs, emphasizing the urgency of early and sustained policy responses. Collectively, these lessons highlight the importance of stricter control policies to reduce long-term air pollution levels.

Limitations of this research

The present study acknowledges certain uncertainties and limitations that should be considered. Notably, the assessment of ambient air pollution exposure relied on a limited number of fixed monitoring stations (CAMS), which may not fully capture intra-urban spatial variability or neighborhood-level pollution hotspots. Variations in cause-specific mortality and incidence rates exist across different regions. Yet, due to the unavailability of region-specific baseline data in Bangladesh, this study used case-specific incidence rates from the Global Burden of Disease study. For this reason, the study was constrained to use fixed data for the entirety of Bangladesh. The study period also includes 2020 and 2021, when COVID-19 lockdowns likely influenced air pollution and mortality patterns. In this study, mortality data were obtained based on only chronic cause-specific deaths and excluded COVID-19 related deaths. Still indirect pandemic-related effects may influence the air pollution and mortality pattern. Furthermore, due to the unavailability of city-specific GDP estimates in Bangladesh, this study applied national GDP to measure economic loss regarding ambient air pollution. Moreover, this study used single air pollutant (PM_{2.5}) for estimating mortality burdens and economic loss as this kind of pollutant predominates in Asian cities. Besides this, PM_{2.5} data from Barisal were missing for approximately 3.5 months due to intermittent technical issues at the CAMS station; no imputation was applied, and annual averages were derived from available observations, which may have slightly affected the accuracy of the estimated annual concentration.

ABBREVIATIONS

CAMSs- Continuous Air Monitoring Stations; CI- Confidence Interval; CRF- Concentration-Response Function; CVDs- Cardiovascular Diseases; GBD- Global Burden of Disease; GDP- Gross Domestic Product; RR- Relative Risk; PM- Particulate Matter; VLL- Value of Life Lost; VSL- Value of a Statistical Life; WHO- World Health Organization

STATEMENTS AND DECLARATIONS

Ethics approval

Formal ethics approval for this study was granted by the Biosafety, Biosecurity and Ethical Clearance Committee, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh [Ref No: BBEC, JU/M 2025/ 04 (241)].

Conflict of interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Life science reporting

No life science threat was practiced in this research.

AUTHOR'S CONTRIBUTION

Afsana Akter: Conceptualization; Methodology; Data curation; Visualization; Investigation; Formal analysis; Writing- original draft; Writing- review and editing; **Sayed Mohammad Rassel:** Conceptualization; Methodology; Data curation; Visualization; Investigation; Formal analysis; Writing- original draft; Writing- review and editing; **Tarekul Islam:** Methodology; Data curation; Writing-original draft; Writing- review and editing; **Md Ziaul Haque:** Writing-original draft; Writing- review and editing; **Md. Iqbal Kabir:** Writing-original draft; Writing-review and editing; **Cui Guo:** Writing-original draft; Writing- review and editing; **James A. Hall:** Writing-original draft; Writing- review and editing; **Suzanne E. Bartington:** Writing-original draft; Writing- review and editing; **Zongbo Shi:** Writing-original draft; Writing-review and editing; **Md. Shakhaoat Hossain:** Conceptualization; Methodology; Investigation; Supervision; Validation; Writing- original draft; Writing- review and editing.

REFERENCES

- Abbas, R. A. H., Shehata, N., Elrahman, E. A., Salah, H., Abdelzaher, M. A., & Science, E. (2021). *Egyptian Journal of Chemistry*. 64(12), 7529–7537. <https://doi.org/10.21608/EJCHEM.2021.89060.4276>
- Abdelzaher, M. A., Farghali, A. A., & Hamouda, A. S. (2024). Effective impact of nano - plastic - waste incorporated with nanotitina on the physical , mechanical and microstructural properties of white cement pastes composites for progressing towards sustainability. *Scientific Reports*, 0123456789, 1–13. <https://doi.org/10.1038/s41598-024-62661-4>
- Aktar, M., & Shimada, K. (2014). *Health and Economic Assessment of Air Pollution in Dhaka , Bangladesh*. July 2006, 1–15. https://www.researchgate.net/publication/242343262_Health_and_Economic_Assessment_of_Air_Pollution_in_Dhaka_Bangladesh#fullTextFileContent
- Anenberg, S. C., West, J. J., Horowitz, L. W., & Tong, D. Q. (2010). The Global Burden of Air Pollution on Mortality: Anenberg et al. respond. In *Environmental Health Perspectives* (Vol. 118, Issue 10, pp. A424-5). <https://doi.org/10.1289/ehp.1002397R>
- Ashraful Haque, H., Huda, N., Zaman Tanu, F., Sultana, N., Shahid Hossain, M. A., & Hasinur Rahman, M. (2017). Ambient Air Quality Scenario in and Around Dhaka City of Bangladesh. *Barisal University Journal Part, 1*(1), 203–218. https://bu.ac.bd/uploads/BUJ1V4I1/16_Hafiz_Ashraful.pdf
- Bari, N. M., Bari, M. N., Nadim, K. M., & Shagor, H. (2016). *Comparative Study on Air Quality of the Divisional Cities of Bangladesh*. April. <https://doi.org/10.13140/RG.2.2.32453.45280>
- Basith, S., Manavalan, B., Shin, T. H., Park, C. B., Lee, W.-S., Kim, J., & Lee, G. (2022). The Impact of Fine Particulate Matter 2.5 on the Cardiovascular System: A Review of the Invisible Killer. *Nanomaterials (Basel, Switzerland)*, 12(15). <https://doi.org/10.3390/nano12152656>

- Bayat, R., Ashrafi, K., Shafiepour Motlagh, M., Hassanvand, M. S., Daroudi, R., Fink, G., & Künzli, N. (2019). Health impact and related cost of ambient air pollution in Tehran. *Environmental Research*, 176(June). <https://doi.org/10.1016/j.envres.2019.108547>
- Chen, J., & Hoek, G. (2020). Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis. In *Environment International* (Vol. 143, Issue June, p. 105974). Elsevier. <https://doi.org/10.1016/j.envint.2020.105974>
- Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., ... Forouzanfar, M. H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *The Lancet*, 389(10082), 1907–1918. [https://doi.org/10.1016/S0140-6736\(17\)30505-6](https://doi.org/10.1016/S0140-6736(17)30505-6)
- Etchie, T. O., Sivanesan, S., Adewuyi, G. O., Krishnamurthi, K., Rao, P. S., Etchie, A. T., Pillarisetti, A., Arora, N. K., & Smith, K. R. (2017). The health burden and economic costs averted by ambient PM(2.5) pollution reductions in Nagpur, India. *Environment International*, 102, 145–156. <https://doi.org/10.1016/j.envint.2017.02.010>
- Guan, Y., Xiao, Y., Rong, B., Zhang, N., & Chu, C. (2021). Long-term health impacts attributable to PM_{2.5} and ozone pollution in China's most polluted region during 2015–2020. *Journal of Cleaner Production*, 321(September), 128970. <https://doi.org/10.1016/j.jclepro.2021.128970>
- Guo, C., Yu, T., Bo, Y., Lin, C., Chang, L.-Y., Wong, M. C. S., Yu, Z., Lau, A. K. H., Tam, T., & Lao, X. Q. (2022). Long-term Exposure to Fine Particulate Matter and Mortality A Longitudinal Cohort Study of 400,459 Adults. *Epidemiology (Cambridge, Mass.)*, 33(3), 309–317. <https://doi.org/10.1097/EDE.0000000000001464>
- Hadei, M., Shahsavani, A., Krzyzanowski, M., Querol, X., Stafoggia, M., Nazari, S. S. H., Jafari, A. J., Yarahmadi, M., Kermani, M., & Khosravi, A. (2020). Burden of mortality attributed to PM_{2.5} exposure in cities of Iran; contribution of short-term pollution peaks. *Atmospheric Environment*, 224, 117365. <https://doi.org/https://doi.org/10.1016/j.atmosenv.2020.117365>
- Hammitt, J. K., & Robinson, L. A. (2011). The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. *Journal of Benefit-Cost Analysis*, 2(1), 1–29. <https://doi.org/DOI:10.2202/2152-2812.1009>
- Han, C., Xu, R., Ye, T., Xie, Y., Zhao, Y., Liu, H., Yu, W., Zhang, Y., Li, S., Zhang, Z., Ding, Y., Han, K., Fang, C., Ji, B., Zhai, W., & Guo, Y. (2022). Mortality burden due to long-term exposure to ambient PM(2.5) above the new WHO air quality guideline based on 296 cities in China. *Environment International*, 166, 107331. <https://doi.org/10.1016/j.envint.2022.107331>
- IHME. (2021). *VizHub - GBD Compare - Interactive data visualise*. <https://vizhub.healthdata.org/gbd-compare/>
- IQAir. (2022). *Air quality in Dhaka*. <https://www.iqair.com/bangladesh/dhaka>
- Khandker, S., McGushin, A., & Abelsohn, A. (2022). *Air Pollution in Bangladesh and Its Consequences* (pp. 1–14). <https://doi.org/https://doi.org/10.21203/rs.3.rs-1184779/v1>
- Khatun, M. S. (2024). *Breathing Through Time : 9 Years Apart - Assessing and Comparing Air Quality in Khulna , Bangladesh : 2013 to 2021*. 13(5).
- Lee, B.-J., Kim, B., & Lee, K. (2014). Air pollution exposure and cardiovascular disease. *Toxicological Research*, 30(2), 71–75. <https://doi.org/10.5487/TR.2014.30.2.071>
- Lu, X., Yao, T., Fung, J. C. H., & Lin, C. (2016). Estimation of health and economic costs of air pollution over the Pearl River Delta region in China. *Science of the Total Environment*, 566–567, 134–143. <https://doi.org/10.1016/j.scitotenv.2016.05.060>
- Macrotrends. (2024). *Dhaka, Bangladesh Metro Area Population 1950-2024*. <https://www.macrotrends.net/global-metrics/cities/20119/dhaka/population#:~:text=The current metro area population,a 3.39%25 increase from 2021.>
- Mahmood, S. (2011). Air Pollution Kills 15,000 Bangladeshis Each Year: The Role of Public Administration and Government's Integrity. ... of *Public Administration and Policy Research*, 3(May), 129–140. <http://www.academicjournals.org/jpapr/PDF/pdf2011/May/Mahmood PDF.pdf>
- Mahmud, H. (2020). *Spatial Analysis of the Concentrations of Selected Gaseous Spatial Analysis of the Concentrations of Selected Gaseous Pollutants in Ambient Air of. February*. <https://doi.org/https://www.researchgate.net/publication/353221572 Spatial>
- Maji, K. J., Arora, M., & Dikshit, A. K. (2018). *SC. Process Safety and Environmental Protection*.

- <https://doi.org/10.1016/j.psep.2018.07.009>
- Maji, K. J., Ye, W. F., Arora, M., & Shiva Nagendra, S. M. (2018). PM_{2.5}-related health and economic loss assessment for 338 Chinese cities. *Environment International*, 121(September), 392–403. <https://doi.org/10.1016/j.envint.2018.09.024>
- Maji, S., Ghosh, S., & Ahmed, S. (2018). Association of air quality with respiratory and cardiovascular morbidity rate in Delhi, India. In *International Journal of Environmental Health Research* (Vol. 28, Issue 5, pp. 471–490). <https://doi.org/10.1080/09603123.2018.1487045>
- Mannucci, P. M., & Franchini, M. (2017). Health effects of ambient air pollution in developing countries. *International Journal of Environmental Research and Public Health*, 14(9), 1–8. <https://doi.org/10.3390/ijerph14091048>
- Mashaal, N. M., Abdelzaher, M. A., Awad, M. M., Elwakeel, K. Z., & Hassan, A. A. (2025). Towards sustainability and circular economy : conceptual design model for the water - energy - food nexus in Ferdaws Village , Western. *Innovative Infrastructure Solutions*, 10(6), 1–14. <https://doi.org/10.1007/s41062-025-02002-0>
- Masterman, C. J., & Kip Viscusi, W. (2018). The Income Elasticity of Global Values of a Statistical Life: Stated Preference Evidence. *Journal of Benefit-Cost Analysis*, 9(3), 407–434. <https://doi.org/10.1017/bca.2018.20>
- Masum, M. H., Rahman, S. M. R., & Pal, S. K. (2020). Assessment of Ambient Air Quality in Major cities of Bangladesh. *Parana Journal of Science and Education*, 6(5), 61–67. <https://doi.org/10.7910/DVN/XAV8AB>
- Mitra, J. R., & Czajkowski, K. (2025). Spatiotemporal patterns and hot spots of PM_{2.5} in Bangladesh. *Atmospheric Research*, 315, 107898. <https://doi.org/10.1016/j.atmosres.2024.107898>
- Naimi, N., Sarkhosh, M., Nabavi, B. F., Najafpoor, A., & Musa Farkhani, E. (2024). Estimating the burden of diseases attributed to PM_{2.5} using the AirQ+ software in Mashhad during 2016-2021. *Scientific Reports*, 14(1), 24462. <https://doi.org/10.1038/s41598-024-74328-1>
- Nasari, M. M., Szyszkowicz, M., Chen, H., Crouse, D., Turner, M. C., Jerrett, M., Pope, C. A., Hubbell, B., Fann, N., Cohen, A., Gapstur, S. M., Diver, W. R., Stieb, D., Forouzanfar, M. H., Kim, S. Y., Olives, C., Krewski, D., & Burnett, R. T. (2016). A class of non-linear exposure-response models suitable for health impact assessment applicable to large cohort studies of ambient air pollution. *Air Quality, Atmosphere and Health*, 9(8), 961–972. <https://doi.org/10.1007/s11869-016-0398-z>
- Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., Turkoglu, B., Kumar, G. A., Khare, M., Beig, G., Gupta, T., Krishnankutty, R. P., Causey, K., Cohen, A. J., Bhargava, S., Aggarwal, A. N., Agrawal, A., Awasthi, S., Bennitt, F., ... Dandona, L. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health*, 5(1), e25–e38. [https://doi.org/10.1016/S2542-5196\(20\)30298-9](https://doi.org/10.1016/S2542-5196(20)30298-9)
- Pavel, M. R. S., Zaman, S. U., Jeba, F., Islam, M. S., & Salam, A. (2021). Long-Term (2003–2019) Air Quality, Climate Variables, and Human Health Consequences in Dhaka, Bangladesh. *Frontiers in Sustainable Cities*, 3(July). <https://doi.org/10.3389/frsc.2021.681759>
- Quah, E., & Boon, T. L. (2003). The economic cost of particulate air pollution on health in Singapore. *Journal of Asian Economics*, 14(1), 73–90. [https://doi.org/10.1016/S1049-0078\(02\)00240-3](https://doi.org/10.1016/S1049-0078(02)00240-3)
- Rahman, M. M., Mahamud, S., & Thurston, G. D. (2019). Recent spatial gradients and time trends in Dhaka, Bangladesh, air pollution and their human health implications. *Journal of the Air and Waste Management Association*, 69(4), 478–501. <https://doi.org/10.1080/10962247.2018.1548388>
- Rasel, S. M., Siddique, A. B., Nayon, M. F. S., Suzon, M. S. M., Amin, S., Mim, S. S., & Hossain, M. S. (2024). Assessment of the association between health problems and cooking fuel type, and barriers towards clean cooking among rural household people in Bangladesh. *BMC Public Health*, 24(1), 512. <https://doi.org/10.1186/s12889-024-17971-7>
- Razib, -, Nayeem, A., Hossain, M., & Majumder, A. (2020). PM_{2.5} concentration and meteorological characteristics in Dhaka, Bangladesh. *Bangladesh Journal of Scientific and Industrial Research*, 55(2), 89–98. <https://doi.org/10.3329/bjsir.v55i2.47629>
- Robinson, L. A., Hammitt, J. K., & O’Keeffe, L. (2019). Valuing Mortality Risk Reductions in Global Benefit-Cost Analysis. *Journal of Benefit-Cost Analysis*, 10(Suppl 1), 15–50. <https://doi.org/10.1017/bca.2018.26>
- Sattar, G., Uddin, N., Sabbir SATTAR, G., & UDDIN Associate Professor, N. (2005). Air Pollution in Chittagong City, Bangladesh. *Technology Rhodes Island*, October, 1–3. <https://www.researchgate.net/publication/308230417>

- Syuhada, G., Akbar, A., Hardiawan, D., Pun, V., Darmawan, A., Heryati, S. H. A., Siregar, A. Y. M., Kusuma, R. R., Driejana, R., Ingole, V., Kass, D., & Mehta, S. (2023). Impacts of Air Pollution on Health and Cost of Illness in Jakarta, Indonesia. *International Journal of Environmental Research and Public Health*, 20(4). <https://doi.org/10.3390/ijerph20042916>
- WHO. (2021). *What are the WHO Air quality guidelines?* <https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines>
- WHO. (2022). *Ambient (outdoor) air pollution.* [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)
- Williams. (2020). *Where Does Bangladesh and Dhaka's Air Pollution Come From?* <https://smartairfilters.com/en/blog/bangladesh-dhaka-air-pollution-sources/>
- World Bank. (2024). *OPen World Bank-GDP data.* <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG>
- Xue, Y., Wang, L., Zhang, Y., Zhao, Y., & Liu, Y. (2022). Air pollution: A culprit of lung cancer. *Journal of Hazardous Materials*, 434, 128937. <https://doi.org/https://doi.org/10.1016/j.jhazmat.2022.128937>
- Zakir, M., & Khan, H. (2024). *Significant Fine Dust in the Air of Rajshahi City Corporation.* 15(3), 421–426.