AN EXPLORATORY STUDY TO EXAMINE ABUNDANCE OF $PM_{2.5}$ AND ASSOCIATED DISEASE BURDEN IN BANGLADESH

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ABSTRACT:

This study examined selected disease burdens in Bangladesh associated with particulate matter exposure using gridded population and $PM_{2.5}$ data between 2001 and 2019. The Global Exposure Mortality Model (GEMM) was used to determine hazard ratio (HR) and disease specific mortality. Besides, trend of $PM_{2.5}$ and selected diseases were evaluated. Results revealed that strong seasonality existed in $PM_{2.5}$ with winter exhibited maximum concentration. The trend assessment showed $PM_{2.5}$ was increasing over time. Among five diseases assessed, LRI was most sensitive to an increase of $PM_{2.5}$, followed by IHD, LC, CEV and COPD. Excess mortality was found to be elevating because of $PM_{2.5}$, particularly in major cities. This study could be useful in advancing research in the disease burden attributable to ambient air pollution in Bangladesh.

1. INTRODUCTION

Among the air pollutants, $PM_{2.5}$ is responsible for most morbidity and mortality around the globe (Shaddick et al. 2020). It is also one of the leading causes of death worldwide (Cohen et al. 2017) and increasing exposure to $PM_{2.5}$ is a serious global environmental and health issue (Lim et al. 2020). An opposite pattern in air pollution and emission profile can be seen in developed and developing countries, i.e., developing nations have high ambient $PM_{2.5}$ concentrations with low per capita emission (Han et al. 2021). The impacts of $PM_{2.5}$ are also heterogenous; developing countries are the most affected and contribute significantly to the Global Burden of Disease (GBD) (Cohen et al. 2017).

Although global (van Donkelaar et al. 2021) and regional studies (Shi et al. 2018) improved our understanding of the magnitude of $PM_{2.5}$ across South Asia (SA), differing data and methods inhibit determining accurate and objective information on areas experiencing high/low concentrations of particulate matter (Lim et al. 2020). In addition, it is also difficult to distinguish whether $PM_{2.5}$ is increasing or decreasing over time in a country, experiencing serious air pollution.

In terms of World Health Organization (WHO) Air Quality Guidelines (AQG), 100% population of Bangladesh are exposed to $PM_{2.5}$ above the 2005 AQG (10 $\mu gm/m^3$ annual and 25 $\mu gm/m^3$ daily), and of course, above the 2021 AQG (5 $\mu gm/m^3$ annual and 15 $\mu gm/m^3$ daily) (WHO, 2021). The association between the abundance of $PM_{2.5}$ and exposure to it has both short– and long–term health effects (Tainio et al. 2021). However, there is a serious lack of study associating $PM_{2.5}$ with health hazards in the country, though a couple of recent works estimated the disease burden for the current and long–lasting air pollution in Dhaka city (Sherris et al. 2021; Siddiqui et al. 2020). This study is, therefore, an attempt to fill a void, which can help develop specific policies to reduce air pollution exposure and disease burden in a well–known global climate change hotspot, i.e., Bangladesh.

Given the above backdrop, this study aims to: (i) examine spatiotemporal changes in $PM_{2.5}$ over Bangladesh between 2001 and 2019; (ii) to estimate excess mortality for selected diseases resulting from the abundance of $PM_{2.5}$; and (iii) determine spatiotemporal changes in $PM_{2.5}$ and mortality.

2. DATA AND METHODS

The particulate matter ($PM_{2.5}$), developed by the Atmospheric Composition Analysis Group of Washington University in St. Louis (V5.GL.02) (van Donkelaar et al. 2021), was used in this study. The data is developed by combining Aerosol Optical Depth (AOD) retrievals from the NASA's moderate–resolution imaging spectroradiometers (MODIS), multi–resolution imaging spectroradiometers (MISR), and sea–viewing wide field–of–view sensor (SeaWIFS) instruments with the GEOS–Chem chemical transport model, and then calibrated to global ground–based observations using a Geographically Weighted Regression (GWR).

The study also employed LandScan gridded population data (https://landscan.ornl.gov/) to estimate excess mortality rate, resulting from high $PM_{2.5}$. The gridded population product is developed from the best available demographic (census) and geographic data, remote sensing, and image analysis using a multivariate dasymetric modelling framework. Annual LandScan gridded data for the period 2001–2019 was downloaded from https://landscan.ornl.gov/landscan-datasets.

The long–term $PM_{2.5}$ mortality exposure–response coefficient was estimated by the Global Exposure Mortality Model

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(GEMM), developed by Burnett et al. (2018). Several recent studies used this method to estimate excess mortality rate due to $PM_{2.5}$ at global (Lelieveld et al. 2020; Burnett and Cohen, 2020) and regional scales (Mueller et al. 2021; Xu et al. 2021). The GEMM was developed to reduce the computational burden in estimating age–dependent excess mortality rate from five diseases attributed to $PM_{2.5}$. They are ischemic heart disease (IHD), cerebrovascular disease (CEV), chronic obstructive pulmonary disease (COPD), lower respiratory infections (LRI), and lung cancer (LC). The GEMM models the shape of the association between mortality based on 41 cohorts from 16 countries and population weighted average $PM_{2.5}$ concentrations, varying from lowest in Canada/United States (7.9 µgm/m^3) to highest in India (74.0 µgm/m^3). The cause-specific ERFs[2] are calculated following Burnett et al. (2018):

$$HR_{GEMM}(\Delta Z_i) = \exp\left\{\frac{\hat{\beta}\log(1+\Delta Z_i/\alpha)}{1+\exp[-(\Delta Z_i-\mu/\upsilon)]}\right\}$$
$$\Delta Z_i = \max\{0, z_j - z_{cf}\} \quad (1)$$

where HR is the hazard ratio, z_j is the $PM_{2.5}$ exposure concentration in the j-th grid-cell, z_{cf} represents theoretical counterfactual $PM_{2.5}$ concentration – the minimum $PM_{2.5}$ concentration in all included cohorts for the GEMM. Burnett et al. (2018) estimated the shape of the $PM_{2.5}$–mortality relationship by the set of values (α, μ, ν), and $\hat{\beta}$ by the Cox proportional hazards model for multiple sets of (α, μ, ν). Estimated values for five diseases are shown in Table 1.

Causes of death	β	α	μ	ν
IHD	0.2969	1.9	12	40.2
CEV	0.272	6.2	16.7	23.7
COPD	0.251	6.5	2.5	32
LC	0.2942	6.2	9.3	29.8
LRI	0.4468	6.4	5.7	8.4

Table 1. Parameter estimates for GEMM (Burnett et al. 2018).

$PM_{2.5}$–related mortality can be estimated using the GBD method (Burnett et al. 2018) as:

$$M_{ij} = [(HR_i - 1)/HR_i] \times \gamma_i \times P_i \quad (2)$$

where M_{ij} is $PM_{2.5}$–attributable mortality caused by ith disease, γ_i and P_i are baseline mortality rate and exposed population, respectively, for j-th grid–cell.

Lelieveld et al. (2020) used baseline mortality for IHD, CEV, COPD, LRI, LC as 22,845, 23,646, 14,612, 4,651 and 50,488 for total population of Bangladesh (160.9 million) in 2015. The same values are used in this work as the baseline mortality rate.

3. RESULTS

3.1 Spatiotemporal variability

Spatial distribution of annualized $PM_{2.5}$, averaged over 2001–2019, is shown in Figure 1, which indicates that $PM_{2.5}$ is higher than the recommended level by the Bangladesh government (15 µgm/m^3) almost all over Bangladesh, except elevated areas in far north, northwest, and southeast. Contrarily, it is exceedingly high (>50 µgm/m^3) in the central, central west and southwest coastal regions. Note that Dhaka and Chittagong metro areas experience high concertation than other cities because of intense anthropogenic activities. Monthly variation of $PM_{2.5}$ reveals that winter (Dec–Feb) has a maximum concentration than summer (June–Sept). Importantly, the concentration of $PM_{2.5}$ is tremendously high in January (130 µgm/m^3) relative to other months. With the onset of monsoon, which brings copious rainfall to the country, $PM_{2.5}$ concentration reduces significantly i.e., <25 µgm/m^3 in August (Figure 2).

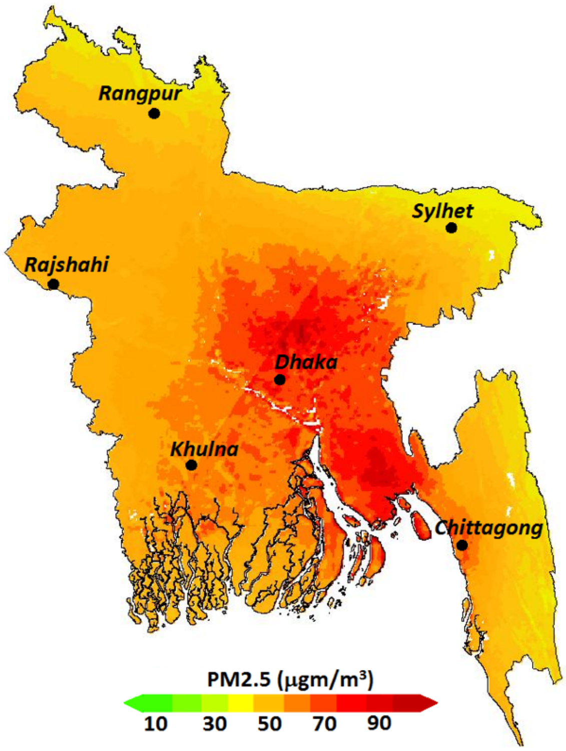
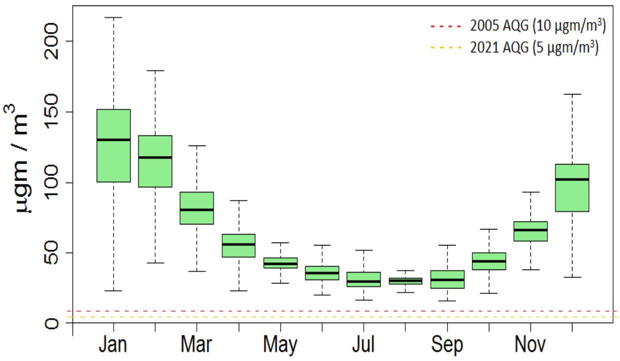


Figure 1. Spatial distribution of $PM_{2.5}$ in Bangladesh, averaged over 2001–2019.

Bangladesh receives an average of 250 mm rainfall during the monsoon season, which results in the reduction of $PM_{2.5}$ concentration. Since rainfall is rare during winter, a sharp rise of the outdoor $PM_{2.5}$ concentration is observed.



[2] Exposure–response function (ERF) defines the relationship between human exposure to $PM_{2.5}$ levels over a period and its effect on human health (Aunan, 1996).

Figure 2. Boxplot, showing monthly $PM_{2.5}$ concentration in Bangladesh.

3.2 Impacts of $PM_{2.5}$ on diseases

The relationship between $PM_{2.5}$ and the hazard ratio (HR)[3] of selected diseases is shown in Figure 3. It exhibits LRI is highly sensitive to particulate matter, followed by IHD, LC, CEV, and COPD. These curves further indicate an exponential increase of HR to all diseases with an increase of $PM_{2.5}$ concentration, pointing to a greater risk of disease with an increase of lower threshold value (15 µgm/m³) of $PM_{2.5}$.

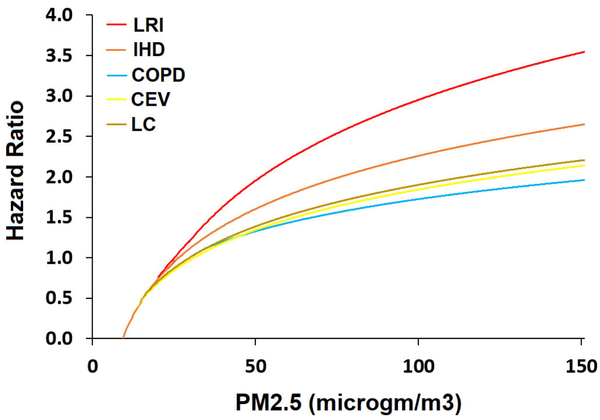


Figure 3. Relationship between $PM_{2.5}$ concentration and hazard ratio of selected diseases.

3.3 Trends in $PM_{2.5}$

Changes in annual, winter and summer $PM_{2.5}$ in Bangladesh are shown in Figure 4, demonstrating an increase in the annual and seasonal concentration over time. Note, however, that its increase was high prior to 2010, and gradually stabled in recent years. Spatial distribution of annual and seasonal $PM_{2.5}$ over Bangladesh for three representative years (2001, 2010 and 2019) is shown in Figure 5. Non–parametric Sen's slope was used to determine trend of $PM_{2.5}$ concentration, which indicates an increasing trend of annual $PM_{2.5}$ by 1.08 (µgm/m³). Similarly, winter and summer values are estimated to increase at a rate of 1.66 and 0.57 µgm/m³/year. Mann–Kendall (MK) test revealed that all changes are significant at $p<0.01$.

3.4 Spatiotemporal changes in hazard ratio (HR)

Changes in HR of selected diseases associated with $PM_{2.5}$ for the period 2001–2019 are shown in Figure 6. A similar increasing pattern in the HR for all diseases is also noticed. Trends in HR of five diseases are shown in Table 2. The increase in HR of all diseases is found at a significant level of >0.01. An increase in HR is highest for LRI (0.021/y), followed by IHD and the lowest for COPD (0.008/y). Spatial distribution of HR for five diseases, resulting from $PM_{2.5}$, for three representative years are shown in Figure 7, suggesting a higher HR for all diseases in the central and central west of the country. The high HR values are noticed to have expanded over time in all directions, particularly to the southwest.

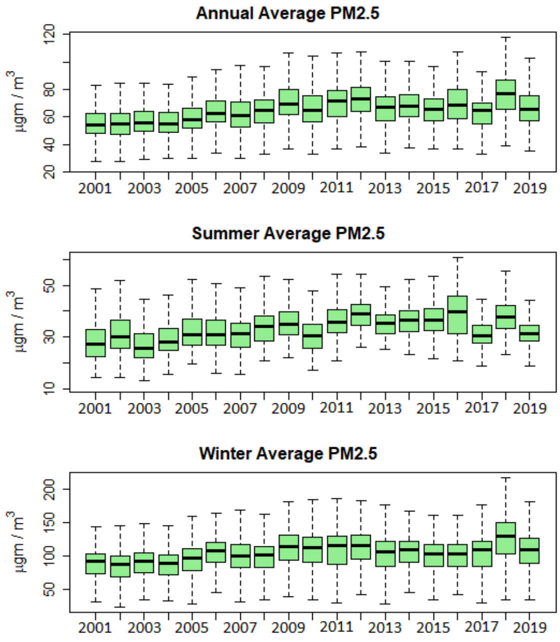


Figure 4. Temporal variability of annual, winter and summer $PM_{2.5}$ during 2001–2019.

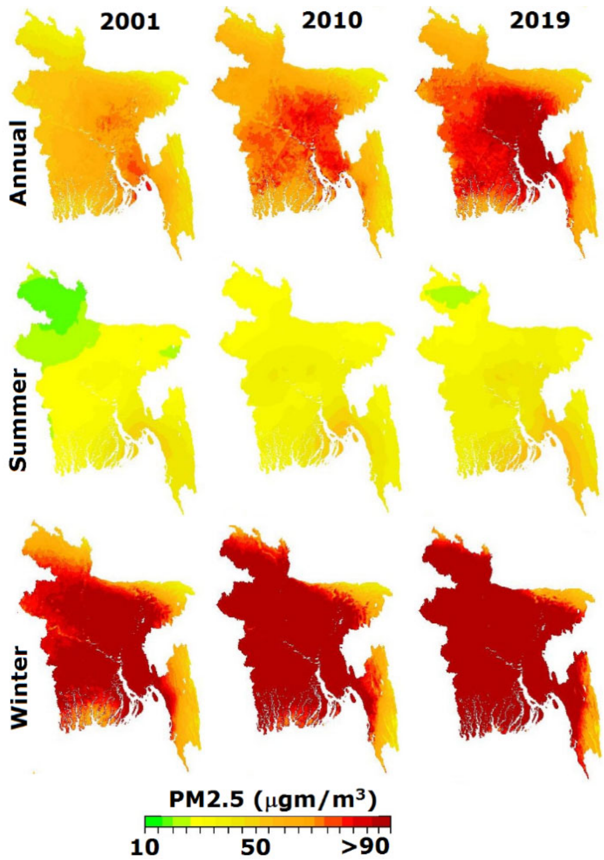


Figure 5. Spatial distribution of annual, summer and winter $PM_{2.5}$ for three representative years.

[3] The hazard ratio is defined as the hazard in the exposed groups divided by the hazard in the unexposed group (Hernan, 2010).

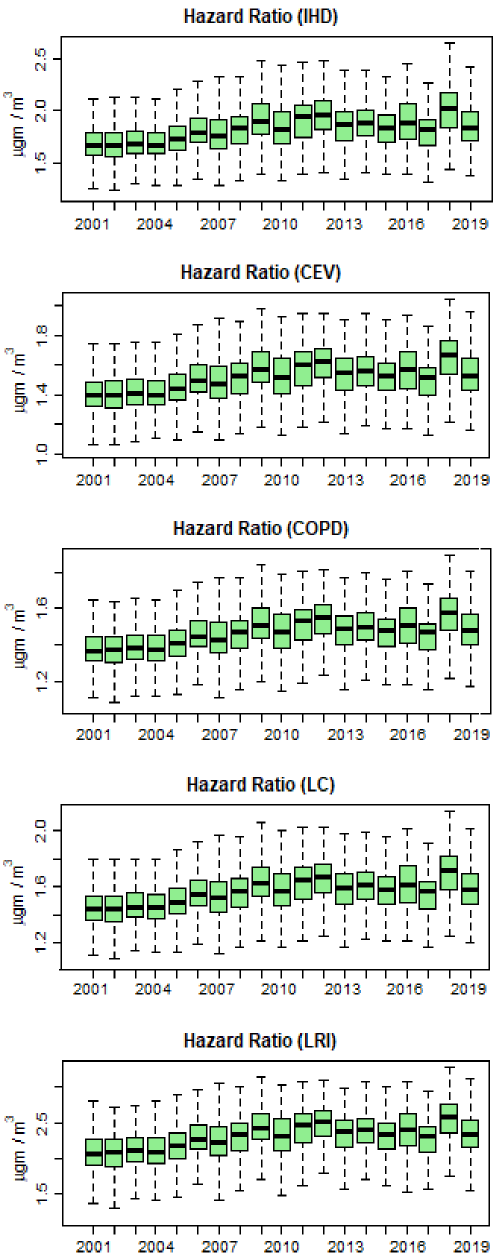


Figure 6. Changes in hazard ratio of five diseases due to $PM_{2.5}$ over the period 2001–2019.

Disease	Hazard Ratio (HR)	Mortality/10^5 person
IHD	0.014*	46.77*
CEV	0.011*	53.62*
COPD	0.008*	28.86*
LC	0.011*	10.78*
LRI	0.021*	101.64*

*Significance at p<0.01

Table 2. Trends in hazard ratio and mortality associated with $PM_{2.5}$.

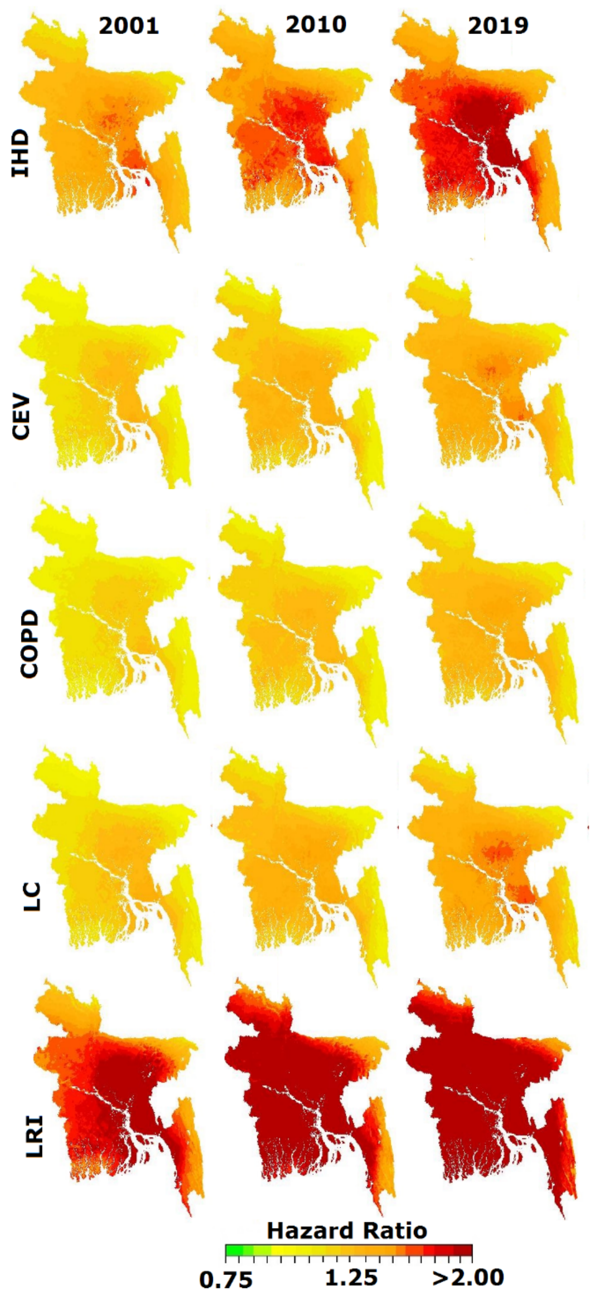


Figure 7. Spatial distribution of hazard ratio (HR) of selected diseases due to $PM_{2.5}$ for three representative years.

3.5 Spatiotemporal changes in mortality due to $PM_{2.5}$

The excess mortality appears to increase in Bangladesh with an increase in $PM_{2.5}$ concentration (Figure 8). Table 2 shows an increase in 101.64 deaths per 100,000 people from LRI each year during 2001–2019. Similarly, an increase in CEV deaths every year is estimated to be 53.62, while the corresponding increase in deaths for IHD, COPD and LC are 46.77, 28.86 and 10.78 persons (Table 2). MK trend statistics reveals that an increase in mortality due to all diseases are significant at $p<0.01$. Spatial distribution of mortality for five diseases attributed to $PM_{2.5}$ in three representative years is shown in Figure 9, indicating higher mortality for all diseases, especially in the major cities.

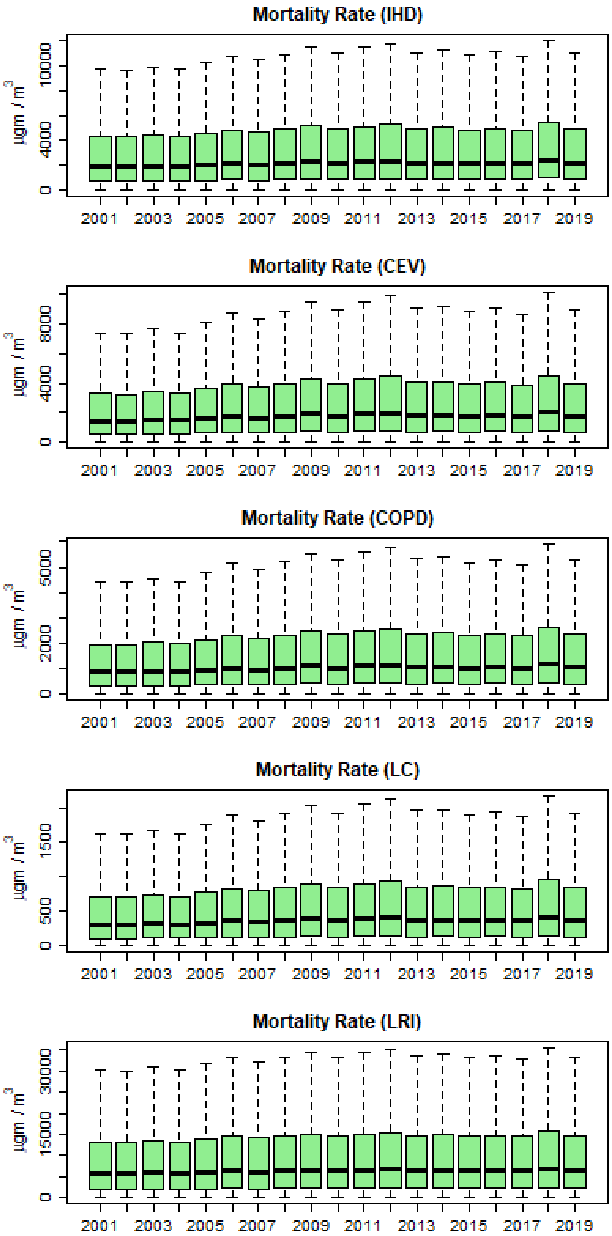


Figure 8. Changes in excess mortality due to $PM_{2.5}$, 2001–2019.

4. DISCUSSION

This study attempted to assess spatiotemporal variations in $PM_{2.5}$ and premature mortality due to particulate matter in Bangladesh. The air quality of South and Southeast Asia (SSEA) is characterized by high concentrations of $PM_{2.5}$, resulting from combustion emissions from various sources (Shi et al., 2018a). The population density in the region is much higher than in other regions of the world. Exposure of a large population to high $PM_{2.5}$ contributed to 59% of the total global deaths and loss of life–years in SSEA (Cohen et al., 2017). The highest premature death rates attributable to $PM_{2.5}$ among the SSEA region are observed in North India and Bangladesh (Shi et al., 2018b). With a population density of 1265 person/km^2, Bangladesh ranks 6th densely populated country in the world. Cohen et al. (2017) estimated population–weighted annual average $PM_{2.5}$ concentration of 89 μgm/m^3 for Bangladesh, which is one of the highest at global scale.

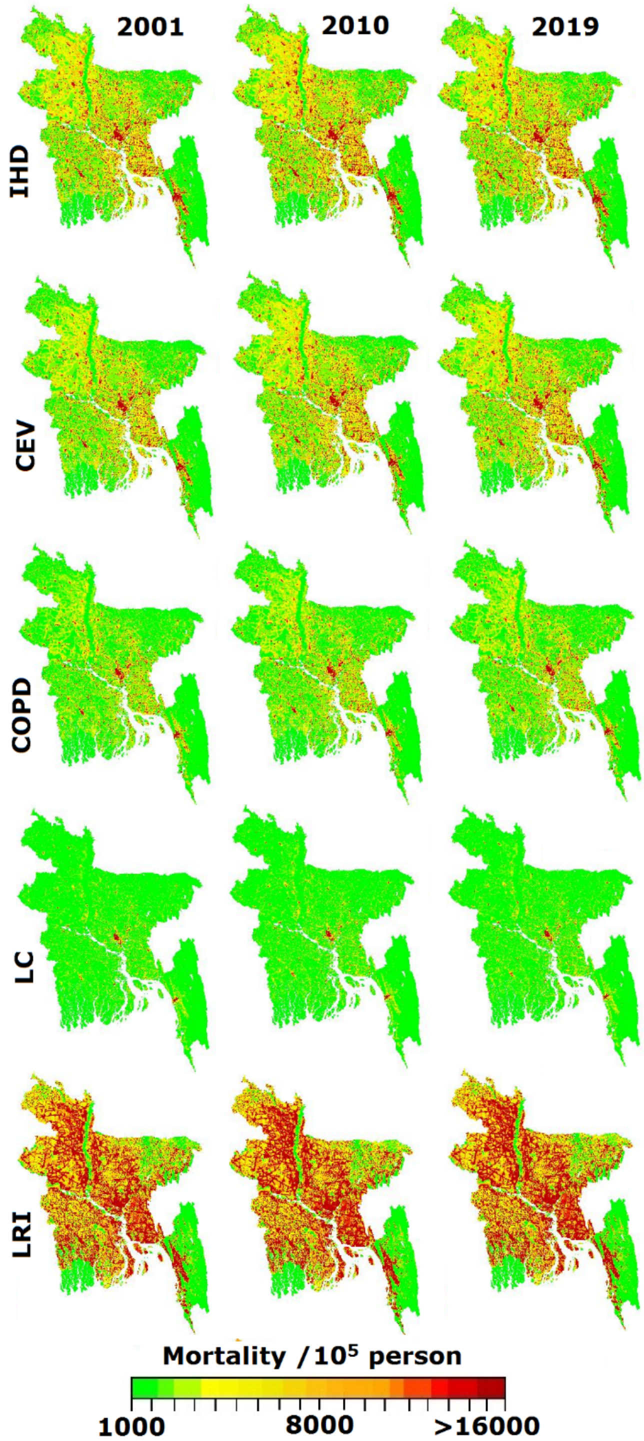


Figure 9. Spatial distribution of excess mortality associated with $PM_{2.5}$ for three representative years.

The consistently high $PM_{2.5}$ concentration and dense population made the premature death rate extremely high in the country. According to the Health Effects Institute (2017), Bangladesh experiences some of the largest increases in $PM_{2.5}$–attributable premature deaths, on the order of 60% globally, which is higher than India (50%), surrounding Bangladesh.

The current study revealed a gradual increase in $PM_{2.5}$ concentration in Bangladesh, indicating a deterioration of the pollution burden. The mean $PM_{2.5}$ of Bangladesh was 54.88 μgm/m^3 in 2001, which increased to 66.04 in 2019. Trend analysis showed an increase in $PM_{2.5}$ concentration by 1.08 μgm/m^3 or 2.03% per year at $p<0.01$ during 2001-2019. This result is in accord with $PM_{2.5}$ trend, estimated by Dey et al. (2020) in India. They found an increase in $PM_{2.5}$ over Indian region, surrounding Bangladesh by >1.0 μgm/m^3 per year. However, this is much higher compared to the global increase in $PM_{2.5}$ concentration by 0.77 μgm/m^3 per year (Shaddick et al., 2020).

Population of Bangladesh increased by nearly 1.1% from 2001 to 2019. An increase in both population and $PM_{2.5}$ concentration caused a rise in 101.64 deaths per 100,000 people from LRI each year. Similarly, an increase in CEV, IHD, COPD and LC deaths was 53.62, 46.77, 28.86 and 10.78 persons during the study period (2001–2019). The increases were from the baseline mortality for IHD, CEV, COPD, LRI, LC as 22,845, 23,646, 14,612, 4,651 and 50,488 for total population of 160.9 million, indicating an average increase in $PM_{2.5}$-mortality by 3.6% during 2001–2019. Jia et al. (2021) estimated an increase in $PM_{2.5}$–mortality in India by 2.7% during 1998–2015. Results however indicated a higher increase in premature mortality attributable to $PM_{2.5}$ in Bangladesh than in India.

Brick kilns, vehicular emissions, coal–fired power plants, and industrial activities are major sources of $PM_{2.5}$ pollution in Bangladesh. The brick kilns and high vehicular activities have made Dhaka city's pollution highest in the country. A recent study revealed that brick kilns, surface dust, and vehicle emissions contribute about 85.0% of local air pollution in Dhaka. The vehicle emissions in the road connecting Dhaka to the port city Chittagong, which is also country's second largest city, have made high pollution zone elongated from Dhaka towards Chittagong. In the future, the chemical transport and dispersion model can be used for the back–extrapolation of pollution to understand its evolution. However, study indicated that brick kilns and vehicular emissions are major source of pollution in the central region of Bangladesh. The country needs action towards emission reduction from brick kilns and vehicles to improve air quality and reduction of premature deaths caused by particulate matter.

5. CONCLUSION

Findings of this work indicated that strong seasonality existed in the occurrence of $PM_{2.5}$ with winter exhibited maximum concentration. Citizens of major cities were experiencing highest level of ambient $PM_{2.5}$ because of rapid urban areal expansion, industrialization, and loss of green coverage (Han et al. 2021; Lim 2020). Like other South Asian countries, exposure to severe air pollution in the country is one of the highest, which was in increasing trend (Salam et al. 2021; Siddiqui et al. 2020). The analysis of the GEMM hazard ratio for selected diseases indicated that lower respiratory infections (LRI) were highest than other disease analysed (Figure 7). This study also revealed that the burden of diseases was increasing over time, which has serious implications for a densely populated country like Bangladesh (Han et al. 2021). Given a very limited number of studies about disease burden associated with $PM_{2.5}$ exposure in Bangladesh, results of this work are expected to be useful in advancing research estimating disease and economic burdens attributable to ambient air pollution in Bangladesh.

Major conclusions of this study are:

- $PM_{2.5}$ was in increasing trend since 2001 and winter exhibited maximum concentration, especially in major cities like Dhaka and Chittagong

- LRI was highly sensitive to $PM_{2.5}$ followed by IHD, LC, CEV and COPD. An increase of $PM_{2.5}$ was shown to elevate the disease burden of the country

- The increase of hazard ratio (HR) was highest for LRI (0.021/year) and lowest for COPD (0.008/year). The central and central–west parts of the country were having higher HR than other parts for all diseases examined

- Excess mortality associated with $PM_{2.5}$ was increasing, however, an increase of LRI (101.64 deaths for 100,000 people) was attributed to ambient air pollution and major cities had higher mortality

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