Evaluating the Disease Burden Linked with Short-term Exposure to Atmospheric Coarse Particles (PM$_{10}$) in the City of Midnapore in West Bengal, India from 2019 to 2020: A Case Study

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Abstract: Atmospheric coarse particles (PM$_{10}$) are 2.5 to 10 microns in diameter; the major contributor to urban as well as rural atmospheric pollution. The primary sources of atmospheric coarse particles (PM$_{10}$) are agricultural products (soil and organic carbon), traffic re-suspension (road dust), burning of domestic fuels, industrial combustion products (elemental carbon), construction, and mining products. Short-term and long-term exposure to inhaled atmospheric coarse particles (PM$_{10}$) plays many detrimental roles in human health and also health damage; directly or indirectly affecting vital organs/systems in the human body (mainly the cardiopulmonary system). The purpose of this study is to evaluate the disease burden by estimating relative risk (based on each current annual PM$_{10}$ concentration obtained from each air monitoring station by using Plantower particulate matter sensor in Midnapore city), the attributable fraction of deaths, and the expected number of deaths due to short-term exposure to PM$_{10}$ for all-cause of all ages. This study included the required annual PM$_{10}$ concentrations (μg/m$^3$) for Midnapore city in 2019 and 2020 (collected by using Plantower particulate matter sensor PMS3003, and PMS5003), PM$_{10}$ exposed population data (collected from Midnapore municipality), and death data for the concerned city (which was collected from the Health Ministry, Government of West Bengal). The percentage of increased risk of death per 10 μg/m$^3$ of exposure to PM$_{10}$ is 0.8% (better to use a 95% confidence interval to eliminate statistical uncertainty) standardized by Bart Ostro (2004) expressed as a concentration-response coefficient (β) under the concentration-response functions, which is used to estimate the relative risk (RR) from PM$_{10}$ exposure. The results of the RR estimate the attributable fraction of death. The expected number of deaths due to short-term exposure to PM$_{10}$ is estimated by multiplying baseline mortality (deaths/person/year) and exposed population with AF results. The results show that the annual average PM$_{10}$ concentration (μg/m$^3$) exceeded both WHO guidelines and India's NAAQSs in Midnapore city in the corresponding years. The results show that the expected number of premature deaths linked with short-term exposure to PM$_{10}$ ranged from 42 to 69 per year. To reduce the burden of PM$_{10}$ disease in the coming days, it is imperative to adopt the necessary policies to control the main source of particulate emissions in the respective cities.

Keywords: atmospheric coarse particles (PM$_{10}$), relative risk, attributable fraction, death rate, short-term exposure, Midnapore city

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1. Introduction

The disease burden of a city or country provides essential information on how the population or sub-population (e.g., children or the elderly) of that city or country distributes the burden and how to make people better aware and keep the body healthy and strong. But currently, urban air pollution is one out of the 19 major risk factors for burden disease in middle-income countries (such as India) [1]; where atmospheric pollution is responsible for 3.1 million deaths worldwide and 3.2% for the global burden of the disease [2]. According to the WHO report (2018), particulate matter (especially particle size less than 10 microns in diameter) is one of the most important ambient air pollutants in urban areas that can easily enter the lungs. Extremely risky particle particulate matter (PM) is a global problem that adversely affects the bodies of people of any age in all nations. Particulate matter (PM), a combination of solid and fluid particles in ambient air that exists especially in urban environments, is
divided into four parts by size: settled particles (diameter ranges between 10 to 40 microns), coarse particles (diameter ranges between 2.5 to 10 microns), fine particles (diameter ranges between 1 to 2.5 microns) and ultrafine particles (diameter ranges between 0.005 to 0.1 microns) [3]. Among the various types of the particulate matter mentioned, atmospheric coarse particles often referred to as PM10, the main sources of atmospheric coarse particles (PM10) are agriculture products (soil, and organic carbon), traffic resuspension (road dust), tire and break products, windblown dust, industrial combustion products (elemental carbon), construction, and mining products, wind-land fires and volcanoes, plant debris and, also, fungal spores [4]. In terms of population-weighted averages, the highest amount of PM10 is emitted from traffic (approximately 34 %) in urban areas of India [5]. Unlike fine particles, atmospheric coarse particles (PM10) are suspended for a short time (minutes to days) in the surrounding air and can travel up to 1 to 100 kilometers from the source [6]. The substance intricacy of all the particulate matter relies upon its source, or the molecule antecedents, and also on environmental conditions [7]. The mass concentration of particulate matter (PM) in the ambient air around a residential urban area is strongly linked with climatic parameters such as wind speed, wind direction, precipitation, temperature, relative humidity, and atmospheric pressure in different seasons which can influence health outcomes [8,9,10]. The hazardous effects of atmospheric pollutants (i.e., particulate matter) on human health mainly play an important role in its size, quantity, surface, and chemical complexity [11]. Short-term and long-term exposure to inhaled atmospheric coarse particles (PM10) plays many detrimental roles in human health and also health damage; directly or indirectly affecting vital organs/systems in the human body (mainly the cardiopulmonary system) [12,13]. The time-series study (1999-2005) showed a strong relationship between particulate pollution (mainly fine and coarse particles) and daily mortality in 112 U.S. cities; studies have shown that particulate pollution increases the risk of all-cause death, heart disease, stroke, and respiratory illness [14]. Previous epidemiological research has found a lot of evidence that short-term exposure to atmospheric coarse particles (PM10) is positively associated with human death [15]. A review article concluded by the major analysis of 196 articles that PM10 was positively associated with all-cause mortality, respiratory mortality, cardiovascular mortality, and cerebrovascular mortality [16].

The purpose of this study is to evaluate the disease burden by estimating the relative risk, the attributable fraction of deaths, and the expected number of deaths due to short-term exposure to atmospheric coarse particles (PM10) for all-cause of all ages. The disease burden of atmospheric coarse particles (PM10) has been applied in this study because the PM10 exposure parameters have been used in numerous epidemiological studies around the world. In light of previous epidemiological studies on all-cause mortality and PM10 exposure; this study selected Midnapore, a historical city in West Bengal, India, at the local level evaluating the disease burden of short-term exposure to atmospheric coarse particles (PM10) in 2019 and 2020. Based on the meta-analysis and expert judgment study evidence, in this study, it is assumed that due to per 10 μg/m³ of PM10 exposure, the risk of death increases by 0.8% (95% Confidence Interval: 0.6% to 1%) for all-cause of all ages [15]. Based on each current annual PM10 concentration obtained from each air monitoring station in Midnapore city (with an area of 18.65 sq. km and a population of around 2 lakhs); estimates the relative risk (RR), the attributable fraction (AF) of deaths, and the expected number of deaths from all-cause of all ages due to PM10 exposure (short-term) for the entire population of the respective year are shown in Table 2. The results regarding the annual PM10 concentration show that the annual average PM10 concentration (μg/m³) exceeded the WHO guidelines and India’s NAAQS in Midnapore city in both years. The highest annual PM10 concentration of 2019 was 77.83 μg/m³ based on S3 station results and of 2020 was 70.09 μg/m³ based on S4 station results. Based on that maximum annual PM10 concentration; the relative risk for 2019 and 2020 was 1.0557 and 1.0484, respectively and the attributable fraction of deaths for 2019 and 2020 was 0.05276 and 0.04616, respectively. The expected number of deaths from all-cause of all ages in 2019 and 2020 were 45 to 78 and 36 to 68 respectively. The results of the study clearly showed that the expected number of premature deaths due to short-term exposure to PM10 in 2019 is higher than in 2020.

2. Materials and Methods

2.1. Study Area

The historical city Midnapore is the headquarters of West Midnapore district in West Bengal, India, located 23m above sea level, with a warm tropical monsoon climate covering an area of 18.36 km². The population in Midnapore municipality comprising of 25 wards was 169127 (as per census 2011), 10% of the populace is under 6 years old. According to the Midnapore municipality report, as per Aadhar estimate total population of Midnapore in the middle of 2021 is 211735 out of 107667 are male and 104068 are female, a population density of 11532.4 (per sq. km). The huge transport and rapid urbanization of the well-connected Midnapore city are the major sources of environmental pollution, where vehicles emissions, burning of domestic fuels, limited industrial activities, and, road dust are the major origin of particulate pollution. At the municipal level, the planning administration takes preventive measures to reduce the harmful effects of urbanization and to provide a hygienic environment for the next generations.

2.2. Assessment of PM10 Concentration in the Ambient Air

Four major densely populated areas, including heavy traffic, were selected in the city of Midnapore to measure the concentration of PM10. The concentrations of PM10 in 2019 and 2020 were measured by using Plantower particulate matter sensor (model numbers: PMS5003 and PMS3003); both sensors were used four times (morning, afternoon, evening, and night) at 1 hour integration time as a daily average. The Plantower PMS3003 sensor (size:
50 mm long × 43 mm wide × 21 mm high; weight: ≈40 g; accuracy from manufacturer report: ± 10% in the 100-500 μg/m³ range) used at S1 and the PMS5003 (size: 50 mm long × 38 mm wide × 21 mm high; weight: ≈42 g; accuracy from manufacturer report: ± 10 μg/m³) used at S2 to S4 station. Both sensors were compact size, portable, low-cost, the digital output was simplified to measure PM₁₀ mass concentration every year. The special feature of the Plantower particulate matter sensor is that the particle size (size ranges between 0.3 and 10 microns) in the air surrounding coastal and urban areas can be measured at a specific integration time (e.g., 1 min, 1 h, 6 h, and 24 h) using the laser light scattering principle. The suboptimal reference analyzer used to select the appropriate average time, long average time (e.g. 24 hours) usually generates a noisy sound signal and consequently indicates the same level of error [17,18]. Commercially available Plantower PMS sensors are selected due to the promising outcomes of ambient and laboratory validation studies and the actual terms of use are present [19,20,21]. Long-term field assessments for measuring PM₁₀ concentration using Plantower sensors are possible even in real-world conditions, such as cold-air pools, wildfires, and dust storms [22].

Figure 1. The geographical location of four selected air monitoring stations (S1 to S4) in Midnapore city, West Bengal, India

The geographical location and coordinates of the four selected stations are shown in Figure 1 and Table 1. Data were collected from 7 March 2019 to 31 December 2020. Since there is no complete PM₁₀ data for 2019, the remaining 65 days of PM₁₀ data for 2019 have been retrieved from the West Bengal Pollution Control Board (WBPCB) as secondary data and the concentration of PM₁₀ (μg/m³) obtained has been fulfilled in all the stations.

Table 1. Station Coordinates of Four Selected Air Monitoring Stations in Midnapore city

| Air Monitoring Station no. | Coordinates                       |
|----------------------------|----------------------------------|
| S1                         | N 22°25'28.4196" E 87°19'09.894" |
| S2                         | N 22°26'25.296" E 87°19'37.65"   |
| S3                         | N 22°25'59.832" E 87°18'27.324"  |
| S4                         | N 22°24'22.896" E 87°19'00.444"  |

2.3. Estimation of Population and Death Data

According to the Midnapore Municipality report obtained from the administrative records, in 2019 and 2020, the combined population of the 25 wards (permanent residents only) was about two lakhs, meaning that the population increased by about 18% from 2011 to 2020. In the absence of information of Midnapore city mortality data, the urban mortality rate (deaths per 1000 population per year) of West Bengal has been taken as the standard for determining the mortality rate of Midnapore city from 2019 to 2020, as the urban area mortality rate was almost the same in the last six years (2011 to 2017) according to the West Bengal Health Ministry report [23]. The death rate in urban areas in West Bengal was 6% (6 deaths per 1000 population per year). Even from 2011 to 2017 there was very little difference between the death rate of West Bengal and the death rate of urban areas in West Bengal.

2.4. Concentration-Response Functions

Evidence of increased death risk related to PM₁₀ exposure has been found in previous epidemiological studies and meta-analyses [20,21,22,23], the reasonable estimate of the risk of death from all causes due to short-term exposure to PM₁₀ ranges from 0.6% to 1% (best point: 0.8%) standardized by Bart Ostro (2004), which represents by the concentration-response coefficient (β) related with concentration-response functions (i.e., changes in the concentration of environmental pollutants provide public health awareness or function in response to adverse health effects) for every 10 μg/m³ exposure to PM₁₀ [15,24]. Relative risk (RR) has been used to assess the percentage of health impact changes due to short-term exposure to PM₁₀ per unit of the population [28]. If the exposure to the annual concentration of each PM₁₀ obtained from the four air monitoring stations is assumed to be single linear exposure of the same magnitude in the same city, then the relative risk is calculated from the following equation 1.
RR = exp[β(X – X₀)]

Where, X = The current annual mean concentration of PM₁₀ (μg/m³), X₀ = baseline concentration of PM₁₀ and concentration-response coefficient (β) = 0.0008 (95% CI: 0.0006 - 0.001).

The following equation 2 is used to calculate the attributable fraction (AF) of deaths to PM₁₀ pollution from the result of relative risk (RR), where 1 is subtracted from the relative risk as the total population is exposed by PM₁₀.

\[ AF = \frac{RR - 1}{RR} \]

The expected number of deaths (ED) due to short-term exposure to PM₁₀ is calculated by the final equation 3, where the baseline mortality rate (BM) with AF and the total number of exposed populations (EP) are multiplied.

\[ ED = BM \times AF \times EP \]

Significantly, there is much uncertainty from such assumptions. It is better to use a 95% confidence interval (95% CI) to eliminate statistical uncertainty for estimating RR. Uncertainty can arise mainly for relative risk estimates, incorrect measurement of population exposure by pollutants, substantial differences in baseline health, as well as other uncertainties from the effects of various pollutants on health [15].

3. Results and Discussion

The minimum, maximum, annual average and standard deviation values of PM₁₀ (μg/m³) obtained from four site-specific air monitoring stations in the city of Midnapore in 2019 and 2020 are shown in Table 2. The results show that the 24-hour average coarse particles (PM₁₀) data obtained from PMS3003 on the S1 differs significantly from the rest of the station, importantly fluctuates day-to-day and also during seasonal times with favorable range. The PM₁₀ values obtained by Plantower (PMS5003) at each station from S2 to S4 were much closer to the average value compared to the PM₁₀ values at the S1 station, which means that the spread of PM₁₀ values from S2 to S4 stations was much less. Significantly, the concentration range of PM₁₀ in each station was much lower in 2020 than in 2019. The highest annual average PM₁₀ concentrations at S3 and S4 stations in 2019 and 2020 were 77.83 μg/m³ and 70.09 μg/m³, respectively; but the annual average PM₁₀ concentration of the remaining stations was the closest. The annual average PM₁₀ concentration at each monitoring station in Midnapore city is higher than both India's NAAQSs (National Ambient Air Quality Standard) and WHO standard, where the annual average NAAQS and WHO standard concentrations are 60 μg/m³ and 20 μg/m³, respectively [27,28]. Again, the Air Quality Index (AQI) and the average PM₁₀ concentration did not provide a good range, with a minimum number of days to all air monitoring stations (S1 to S4) of the corresponding year provides good health effects. Based on India's National Air Quality Index, the maximum number of days provides a satisfactory range (approximately 75% days) as shown in Figure 2 [30]. The PM₁₀ daily cycle from S2 to S4 stations shows that the concentration of PM₁₀ during one-hour integration was higher in the afternoon and evening than in the morning and night, more than 90% days per year. Seasonal variation is also influenced PM₁₀ concentration, significantly higher in cold seasons than in other seasons.

Figure 2. The average PM₁₀ concentration (μg/m³) status is based on India's National Air Quality Index at various air monitoring stations (S1 to S4) in 2019 and 2020

| Station No. | Year | PM₁₀ Concentration (μg/m³) |
|-------------|------|---------------------------|
|             | Min  | Max  | Mean | Standard Deviation (SD) |
| S1          | 2019 | 2.25 | 170  | 73.90 | 14.35 |
|             | 2020 | 2.73 | 162  | 61.90 | 12.62 |
| S2          | 2019 | 14.48| 113  | 75.34 | 3.56  |
|             | 2020 | 12.78| 111  | 64.54 | 9.38  |
| S3          | 2019 | 13.59| 140  | 77.83 | 2.24  |
|             | 2020 | 12.55| 165  | 66.13 | 8.21  |
| S4          | 2019 | 14.36| 136  | 77.11 | 2.11  |
|             | 2020 | 12.39| 118  | 70.09 | 6.48  |
The disease burden of all-cause mortality of all ages linked with short-term exposure to PM$_{10}$, the results evaluated based on each independent annual average PM$_{10}$ concentration ($\mu$g/m$^3$) from individual air monitoring stations are shown in Table 3. For each individual site-specific station in Midnapore city, the results given are almost the same in all the stations of the respective year. The applied equation 1 gives the result of the relative risk (RR) by using annual and background concentrations of PM$_{10}$ and concentration-response coefficient ($\beta$), where suggested $\beta$ coefficient 0.0008 (95% CI: 0.0006 - 0.001) per 10 $\mu$g/m$^3$ PM$_{10}$ exposure. The relative risk (RR) results were found to be 1.05 and 1.04 in 2019 and 2020, respectively. Equation 2 has been applied to the quantitative assessment of the attributable fraction of deaths due to short-term exposure to PM$_{10}$. The attributable fraction of deaths in 2019 is higher than that of 2020 at all stations, in 2019 and 2020 there were attributable fractions of deaths 0.05 and 0.04, respectively. The expected number of premature deaths from short-term exposure to PM$_{10}$ is calculated by the applied equation 3. Due to the absence of death data in the respective cities, the continuous death rate/year in urban areas of West Bengal for the last six years (2011-2017) according to a report by the Ministry of Health (Government of West Bengal), has been assumed to be constant (i.e., 6 deaths per 1000 people) in Midnapore in 2019 and 2020. The estimated baseline mortality (BM) rate is 0.006 (deaths/person/year) and the total number of exposed population (EP) is about 2 lakhs. The results showed that the expected number of death in 2019 was higher than in 2020. In 2019, the highest and lowest estimated (best) premature deaths in S3 and S1 were 63 (95% CI: 47-78) and 59 (95% CI: 45-74), respectively. In 2020, the highest and lowest estimated premature deaths in S4 and S1 were 56 (95% CI: 42-69) and 48 (95% CI: 36-60), respectively. Significantly, the 95% CI value is preferred due to some uncertainties mentioned earlier.

Alternatively, if the two-year concentration of PM$_{10}$ in the four polluted areas is taken as the average in Midnapore city, then the annual average of PM$_{10}$ concentration from 2019 to 2020 is 70.86 $\mu$g/m$^3$ which gives the same results as S4 station in 2020. Therefore, the expected number of deaths per year in Midnapore city is about 42 to 69 due to short-term exposure to PM$_{10}$.

### 4. Conclusions

The study concludes that there is no significant difference in the annual PM$_{10}$ concentrations obtained from PMS3003 and PMS5003, but there is considerable disparity between year-round PM$_{10}$ concentration obtained from PMS5003 at S1, therefore the results of disease burden evaluation at each station are almost significantly identical in the corresponding year based on PM$_{10}$ data. According to the annual PM$_{10}$ data for each station in 2019, the PM$_{10}$ concentration in each station is higher than in 2020. As a result, the relative risk (RR), the attributable fraction (AF) of deaths, and the expected number of premature deaths linked with short-term exposure to PM$_{10}$ were also higher in 2019 than in 2020. The annual average PM$_{10}$ concentration ($\mu$g/m$^3$) exceeded both WHO guidelines and India's NAAQSs in Midnapore city in the corresponding years, increasing the risk of premature mortality and morbidity associated with cardiovascular and respiratory illnesses of all ages, which is much more likely to lead to horrific situations in the coming days. To reduce the burden of PM$_{10}$ disease in the coming days, it is imperative to adopt the necessary policies to control the main source of particulate emissions in the respective cities. Planning administration at the municipal level for environmental development should take preventive measures to reduce particulate emissions and provide a healthy life for future generations.

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