Status of particulate matter exposure in Bangladesh and the preliminary association with airborne microbes

By

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A thesis submitted to the Department of Mathematics & Natural Sciences in partial fulfillment of the requirements for the degree of B.Sc. in Microbiology

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Abstract

In the current world, particulate matter in terms of PM 2.5 and PM 10 exhibits serious human exposure and works as an environmental media, attaching other elements like airborne microorganisms. Using Bangladeshi case studies on particulate matter exposure, this study newly ascertained the relationship between the level/behavior of particulate matter and the airborne microorganism. As a result, almost all of the investigated papers for Bangladesh elevated levels of particulate matter in the unit μgm^{-3} (PM 2.5: outdoor range of 2.33-220; indoor of 14.4-361; PM 10: outdoor of 10.1-1447; indoor 32-472) indoor, compared to local and international standards. The urban settings of Dhaka and the nearest regions, Chittagong, Savar, and Rangpur, presented the highest levels in the country. In rural areas, types of dwellings are identified as the factors accelerating the level and indoor distribution. In Dhaka, bacteria were achieved as the airborne microorganism associated with elevated particulate matter while presenting other pathogens in crowded areas. Internationally, the fungi and antibacterial with meteorology (Saudi Arabia; average PM 2.5 concentrations 60 μgm^{-3}, PM 10 as 159.9 μgm^{-3}; presenting positive correlation of r=0.23 and negative correlation r=-0.2 with microorganisms respectively); allergens, and pathogens during severe smoke events (China), and animal farming (Malaysia, in unit of mgm^{-3} PM 2.5 range is 55.38-61.02; and PM 10 65.38-87.84)) are obtained with correlated with the particulate matter as the airborne microorganism’s settings.

Keywords: Particulate matter (PM); airborne microorganisms, Bangladesh, correlation, factor analysis

1. INTRODUCTION

1.1 Air pollution (particulate matter, PM)

Nowadays, air pollution challenges human beings as a whole and is of many kinds, such as acute and chronic conditions, which invades a more significant number of people in a vulnerable segment and simultaneously leads to heavy mortality and economic costs globally. Air pollutants such as particulate matter or PM (the designations PM2.5 and PM10), ozone, or nitrogen dioxide attack the mucous membranes and other parts of respiratory tracts in the short term, causing from time to time an exacerbation of illness conditions like asthma or chronic obstructive pulmonary disease (COPD), and later result in cardiovascular events like heart attacks and high blood pressure. In chronic use, this factor causes chronic respiratory conditions, cardiovascular diseases like atherosclerosis and stroke, and various types of malignancies. It relies on exposure to carcinogens such as benzene and polycyclic aromatic hydrocarbons. New science is also saying that air pollution is related to problems like Alzheimer's and how old people tend to have more exposure to kinds of dementia and children with developmental delays in between. People, including children, the elderly, pregnant women, and also the economically backward person, face this nearly more; they live in places with high exposure to air and little access to medications. Mechanistically, air pollution inflicts harm through the generation of oxidative stress, inducing systemic inflammation and weakening immune responses so that there is a greater distribution of infection and other related health complications. Air pollution accounts for about 7 million premature deaths yearly; it costs public health and the healthcare system, not to mention the enormous loss of economic productivity. Therefore, a solution to the problem will involve an integrated approach like regulatory frameworks on a national level, a shift from using non-cleaner forms of energy, and individual interventions combined with global cooperation in mitigating far-reaching health and well-being effects.

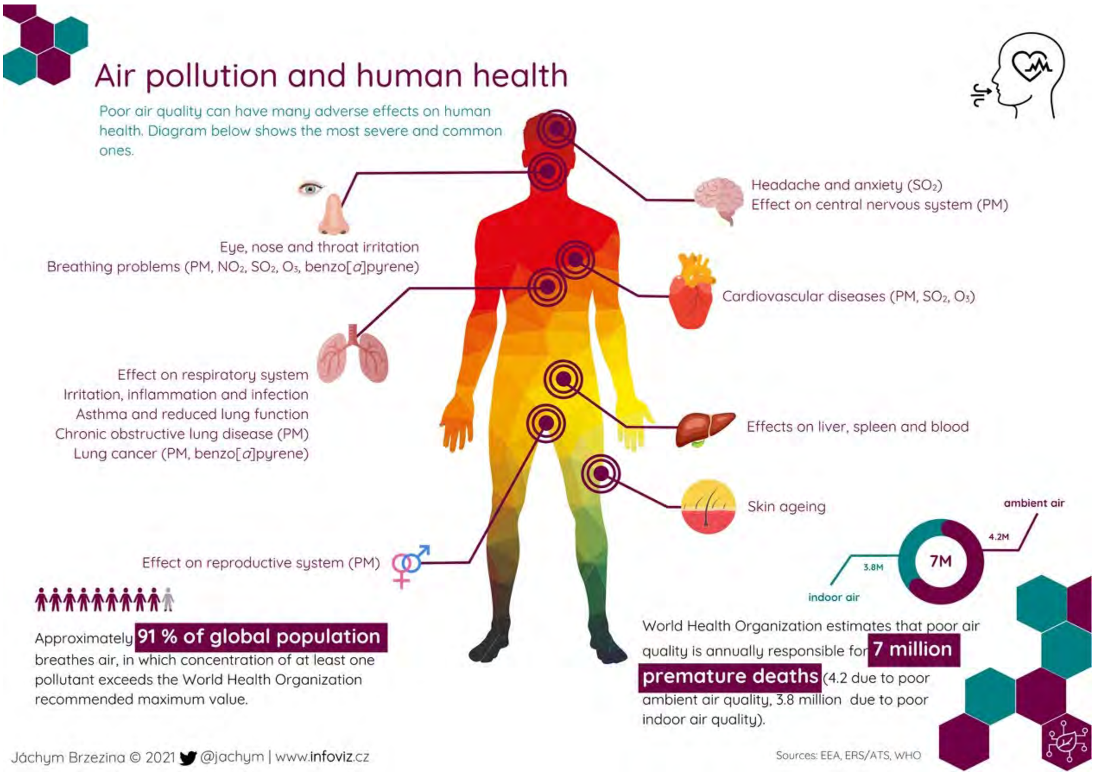

Figure-1: Impact of air pollution(particulate matter) on human health(Jáchym Brzezina, 2022)

When PM enters the body, it can have effects on various organs and systems, not just the respiratory system.

The problems include in the problem of the (a) eyes, nose, and throat; (b) the lungs and respiratory system; (c) the heart – heart and blood vessel diseases, including strokes and hardening of the arteries, are one of the main effects of air pollution.

Emerging evidence suggests PM may also affect the brain and is possibly linked to dementia and cognitive decline. There is also emerging evidence associating air pollution with early-life effects such as low birth weight.

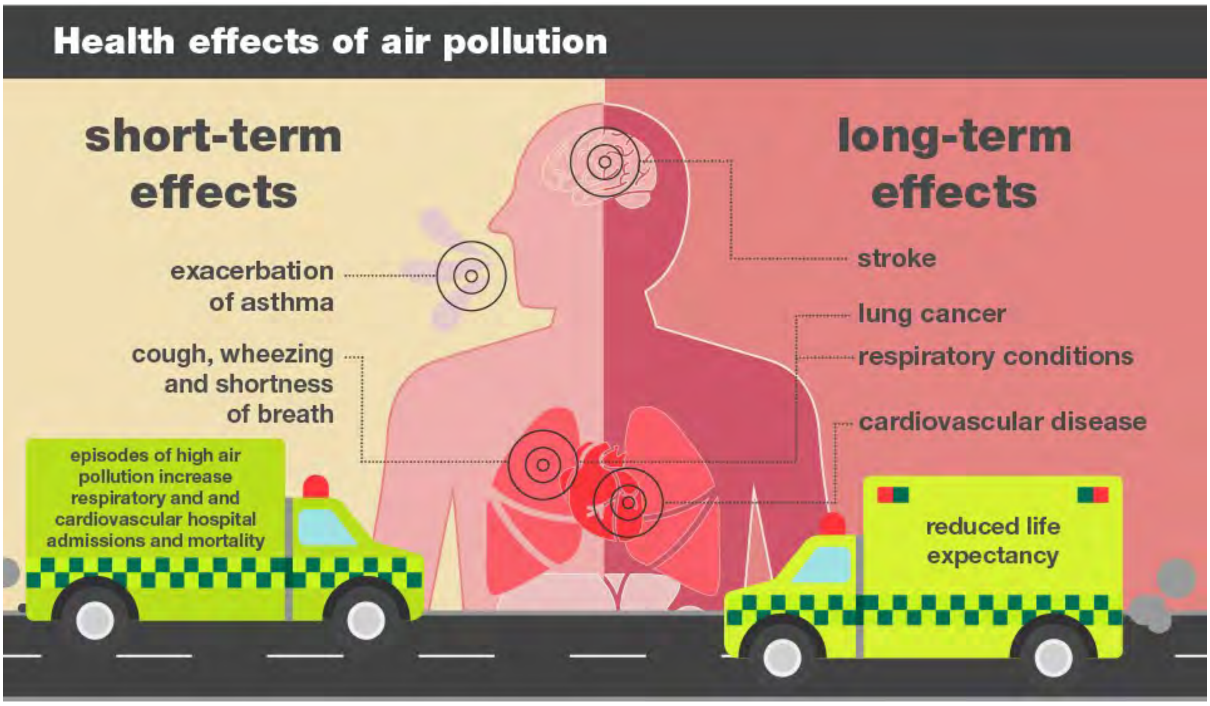

Figure-2: Short and long-term health effects of PM pollutants (Public Health England, 2018)

Different studies focusing on the real measurements of particulate matters in terms of PM 2.5 and PM 10 ascertained potential co-existing mechanisms with microbes and other gases. Thus, using a medium of microbes, this thesis covers the overall review of the particulate matter in Bangladesh and other Asian environments, summarizing the potential airborne contribution of microbes.

1.2 Background and goal of this study

As stated above, particulate matter (PM), being one of the most prevalent environmental pollutants, exhibits serious human exposure (Faherty et al., 2025; Ilenič et al., 2024; Li et al., 2023; Lim et al., 2022; Yu et al., 2023). In Bangladesh, the particulate matters also present profound human exposure to the population (Ahmed et al., 2024; Das, 2023; Dasgupta et al., 2006; Hashem et al., 2024; Partha et al., 2025). While looking at the physical properties, based on the size, formation and attachment mechanism, they often retain the microbiological organism (Cao et al., 2014; Hiwar et al., 2021; Mazlan et al., 2021; Zhai et al., 2018). Thus, considering the multiple pollutants from both chemical and microbiological viewpoints, it is important to ascertain the relationship between the PM, hereafter, the aerosol's behavior, especially the concentrations and the survival time of the microbiological organism associated with the aerosol levels.

This study will first summarize the PM pollution in Bangladesh in indoor and outdoor environments, focusing on the published research papers. Later, this thesis will adopt the microbiological survivals focusing on the PM pollution of Bangladesh as a case study. However, in Bangladesh, there is lacking papers on atmospheric microbes in the relevant fields. Thus, this thesis will look at other countries and regions for fulfilling the relationships.

Finally, the aim of this thesis is-

(a) to newly reviewing the status of particulate matter (PM) pollution and exposures in Bangladesh

(b) to determine the correlation between the concentration of particulate matter and the survival of the microbes focusing on Bangladeshi case studies and international world

(c) to ascertain the factors affecting the microbes' survival on particulate matter

1.3 Methodology

This thesis focused on the review of the literature classified in journal papers, thesis, and reports for collecting cutting-edge and up-to-date information on PM microbes in Bangladesh and abroad. Firstly, the relevant papers were collected by searching the keywords of ‘particulate matter (PM) and aerosol pollution in Bangladesh’, ‘PM pollution in Dhaka city in both indoor and outdoor environment’, ‘status of atmospheric microbes in Bangladesh’, ‘relationship between the concentrations of particulate matters and survival of microbes in the air’ and ‘factor affecting the microbes' survival’. Among the large number of papers, around 30 relevant papers, a few reports and a doctoral thesis of The University of Tokyo were found to be closely associated with this thesis.

The Bangladeshi case studies based on the exposure of particulate matter has been systematically reviewed for Dhaka city and other regions considering the indoor and outdoor environment. Moreover, the living environment of dwelling types, affecting environmental factors, human lifestyle information like cooking behavior, and potential sources from both indoor & outdoor are investigated under this thesis framework.

This thesis uses the results obtained from collected materials to prepare systematic new tables and figures. Relevant figures are inserted in this thesis with an explanation, and an executive discussion and conclusion are described. In all cases, the relevant references and sources of the materials are surely included throughout this thesis paper.

2. RESULTS

2.1 Countrywide status of particulate matter in Bangladeshi regions

This study reviewed the levels and exposure of particulate matter of PM 2.5 and PM 10 across the Bangladeshi environment. Using the related published articles, this study primarily reviewed the overall status of the particulate matter concentrations in Bangladeshi locations and different environments. Apart from determining the countrywide status, the levels and exposure have been compared with the international world.

The study (Rana et al., 2016) focuses on the particulate matter in Dhaka city of Bangladesh and ascertained the PM 10 concentrations in the capital of Dhaka city and the nearest areas. Based on the background of the extreme air pollution situation in Bangladesh, this study investigated the spatiotemporal variations of particulate matter for three years of measurement period. The average PM 10 concentrations for the Dhaka and two adjacent cities (Gazipur and Narayanganj) are given in the above Table 1. The obtained pollution level of PM 10 during the wet season (May to October) was found to be as per the national standards of Bangladesh, however it exceeded WHO guideline value in 50% of the days of that season. While determining the systematic source, the transboundary east Indian region bordering Bangladesh and the north-eastern Indian region bordering Nepal and Nepal, as well as its neighboring areas, presented a high possibility of PM pollution at Gazipur station. Alternatively, this research also explained that the PM2.5 concentration across the regions was about six times higher than the standard values set by the Government of Bangladesh. The areas experienced very elevated levels of PM pollution in 25% of days of dry season when the daily average PM 2.5 concentrations were about 8-13 times higher than WHO guideline values. Finally, as of the local sources of brick kilns, open burning, vehicles, sand fields, Turag rivers, and industries were found to be the sources of higher PM pollution during the dry season.

As of the systematic temporal variabilities of the ambient air quality in Dhaka city of Bangladesh, the study (Begum & Hopke, 2018) sampled PM in semi-residential areas of Dhaka between the years December 1996 and September 2005. The average and the ranges of both PM 2.5 and PM 10 are given in Table 1. The long-term data obtained in this research presented that the air quality of Dhaka city has been stable over the past decade, although the activity and the number of sources, including passenger cars and brick kilns, are increasing. While observing the ratios between PM 2.5 and PM 10, the yearly variation ranged from 0.23±0.09 μgm^{-3} to 0.56±0.13 μgm^{-3}. The study concluded that the Government's policies of banning gasoline and banning of two-stroke engines, in addition to green technology for brick production, resulted in lower levels of PM pollution.

Based on the spatiotemporal analysis and forecasting of air quality in greater Dhaka city, the research study (Rahman & Kabir, 2023) on the air quality indicator was the highest during the dry season, with an average of 128.5 μgm^{-3}, while the lowest concentrations were found to be in the monsoon season, with an average of 19.1μgm^{-3}. The values concerning both the PM 2.5 and PM 10 concentrations as of the average and ranges are provided in Table 1 following the different seasons of the year. This study determined the significant correlation between PM and CO, NO_2, AOD, and AQI, indicating a similar origin of sources.

A study (Islam et al., 2021) following the air quality and meteorological variables of Dhaka city of Bangladesh estimated the PM 2.5 concentrations for three months (March-June) for 2019 and 2020. The average concentration was 70.50 μgm^{-3} with a range of 31.04-122.54 μgm^{-3} in 2019 and 58.44 μgm^{-3} with a range of 33.47-101.06 μgm^{-3} in 2020. The study determined the relative humidity among the meteorological parameters investigated with a significant positive correlation.

As for the air quality investigation in the indoor environment of Dhaka city, a study (Yasmin et al., 2024) determined the air quality and associated factor investigations by estimating the

PM 2.5 concentrations for 43 homes. The continuous monitoring of PM 2.5 concentrations was done over 24 hours. In addition, home characteristics related to home area, cooking type, ventilation practice and window usage, and indoor human activities were included as the indoor factors. PM level 2.5 is shown in Table 1. The estimated average PM 2.5 concentrations were obtained as five times higher than the WHO 24-hour short-term guideline level for ambient air pollutants. The average PM 2.5 concentrations were achieved as 75.69 μgm^{-3}, which is higher than many other regions/countries' situations of Vietnam, London, Spain, India, Texas, Hong Kong, Chile, Nepal, Alaska, France, UAE, Greece, Basel, Helsinki, and Prague as mentioned in this paper. As for the home factor analysis, outdoor air, home area, cooking duration, and cleaning frequency were obtained as significantly related to indoor concentrations, which collectively explained 64% of the variability of indoor PM2.5 levels. While focused on the outdoor impact, outdoor air filtration emerged as the most influential predictor of indoor levels by contributing significantly to indoor concentrations. This research indicated that indoor countermeasure approaches and improved ventilation were the influential factors. The cooking practices of cooking duration and frequency can significantly lower indoor pollution. Alternatively, cleaning dust and lessening the usage of mosquito coils should be other countermeasures.

A study (Roy et al., 2023) investigated the health impact of fine particulate matter exposure on school children in Dhaka (indicated in Table 1). The measurement was conducted from April to November 2018. Relatively higher particulate matter concentrations were obtained in the investigated school premises. Regarding the outdoor impact, a poor correlation was found between indoors and outdoors. This study recommended increasing the knowledge of air pollution.

Using the Eco Tech air sampler, the study (B. A. Begum, 2016) measured PM 2.5 and PM 10 concentrations as a tool for monitoring air quality assessment in Narayanganj and Munshiganj.

The sample collection was done from 14 August to 7 September 2016. Significantly lower PM concentrations in the study areas. In the two regions in Munshiganj named Vati Bolaki and Gowal Goa, average PM 10 concentrations were 33.9±9.49 μgm^{-3} and 34±12.9 μgm^{-3}, respectively. On the other hand, PM 2.5 concentrations were 13.6±5.16 μgm^{-3} and 18.2±8.31 μgm^{-3}, respectively. Furthermore, in Narayanganj, two places were investigated named Pachani and Chorhogla, where the PM 10 concentrations were achieved as 28.6±12.4 μgm^{-3} and 38.5±19.1 μgm^{-3}, respectively, and the PM 2.5 levels were found to be 11±1.84 μgm^{-3} and 19.1±5.34 μgm^{-3}. The study highlighted the source as 50.4 % of the total fine PM originated from biomass burning/brick kilns. High particulate matter concentrations were found only in the winter season. Overall, significantly lower fine particulate matter concentrations were obtained in this study due to the meteorological effect and less anthropogenic activities.

A comparative house-based health impact assessment (Khalequzzaman et al., 2011) was done in an urban and rural environment. Mirpur, as the representative of the urban, and Munshigonj, for the rural, were considered in this research. However, this paper did not clarify the classification of air pollution (as of PM 2.5 and PM 10); only indoor air quality was clarified in units of mgm^{-3}. The dust particle concentration was estimated for these two areas following seasonal variations under the conditions of during and non-cooking conditions. In the urban environment of Mirpur, an elevated average level was obtained as (curing cooking: 1.1±1.1 mgm^{-3}, non-cooking: 0.5±0.04 mgm^{-3}), where the summer expressed a relatively lower level of (cooking: 0.6±0.1, non-cooking: 0.2±0.2 mgm^{-3}). On the other hand, the rural environment expressed a relatively higher level in winter (cooking: 0.3±0.05, non-cooking: 0.2±0.01 mgm^{-3}) than in the summer (cooking: 0.2±0.1 mgm^{-3}, non-cooking: 0.1±0.1 mgm^{-3}). Overall, this study identified the indoor air quality to be lower in urban biomass fueling than in rural.

A study (Kumar et al., 2024) focused on the comparative study of Dhaka city as one of the global megacities. The spatiotemporal variability was assessed in this paper. The level of PM was found to be consistently high in Dhaka city along with occasional higher levels in the surrounding cities. According to this paper, according to the air quality guidelines (BNAAQS), the value of PM 2.5 in the ambient air is 65 for a 24-hour period and 15 on an annual average. However, the WHO air quality guidelines are valued at 15 for a 24-hour period and 5 for an annual period. Following this study's analysis, PM 2.5 concentrations in about half of the studies exceeded the BNAAQS guideline value. Overall, the PM concentrations are higher in the traffic and industrial areas in Bangladesh, whereas the residential and semi-residential areas in Dhaka and other divisional cities presented relatively lower concentrations of PM 2.5. Moreover, this study obtained significant differences in atmospheric PM 2.5, and PM 10 in global megacities. Overall, the Asian and African megacities had elevated levels of PM 2.5 concentrations, whereas the Japanese and American megacities presented lower levels.

Based on the indoor exposure assessment, a study (Md. Mahamudul Hasan, 2025) revealed the PM 2.5 and PM 10 concentrations in Dhaka and Rangpur city. Special focus was given to the types of dwellings. In the modern houses which is one of the representative dwelling types in Bangladesh, the average PM 2.5 and PM 10 concentrations were measured as 225 μgm^{-3} having a range of 33-361 $\mu gm^{-3,}$ and 288 μgm^{-3} having a range of 58-472 μgm^{-3}. In addition, in the area of Rangpur, the lower levels of particulate matter concentrations were found in the representative dwelling types of mud, soil, tin-shed, brick, and modern. The study reported that the annual average PM 2.5 levels in Dhaka city exceeded 100, which is around 20 times elevated compared to the WHO guidelines. Based on the measured data, the average PM 2.5 concentrations were about 40 to 60 times higher than the WHO recommendations. As determined in the rural area of Rangpur, the impact of vehicles was assumed to be lower. Whereas the rural kitchen expressed the PM 2.5 and PM 10 concentrations as 416 μgm^{-3} and 598 μgm^{-3}. The obtained impact in this study for PM pollution was clarified not only for lung cancer but also for shorter survival of lung cancer patients from continued post-diagnosis exposure in Bangladesh.

Table 1: Countrywide status of the exposure (μgm^{-3}) of particulate matter (PM 2.5 and PM 10) in Bangladesh

Places	PM 2.5	Unit	PM 10	Unit	Reference
Dhaka			257.1	μgm^{-3}	(Rana et al., 2016)
Dhaka	34.6 (2.33-220)	μgm^{-3}	96.3 (10.1-426)	μgm^{-3}	(Begum & Hopke, 2018)
Dhaka	19.1-128.2	μgm^{-3}			(Rahman & Kabir, 2023)
Dhaka	33-123	μgm^{-3}			(Islam et al., 2021)
Dhaka	66.9±41.4 17-191.8				(Kumar et al., 2024)
Dhaka city (Home)	75.69 (14.42-296.63)	μgm^{-3}			(Yasmin et al., 2024)
Dhaka city (School)	14.4-64.9	μgm^{-3}	33.8-469.7	μgm^{-3}	(Roy et al., 2023)
Dhaka (Mirpur)	0.2-1.1	mgm^{-3}			(Khalequzzaman et al., 2011)
Dhaka (Houses)	225 (33-361)	μgm^{-3}	288 (58-472)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)
Gazipur			240.3	μgm^{-3}	(Rana et al., 2016)
Savar			699.4 (133-1086)	μgm^{-3}	(Kumar et al., 2024)
Narayanganj			327.4	μgm^{-3}	(Rana et al., 2016)
Narayanganj	6.80-31.2	μgm^{-3}	21-54.9	μgm^{-3}	(B. A. Begum, 2016)
Munshiganj	8.69-29.3	μgm^{-3}	15.1-75.1	μgm^{-3}	(B. A. Begum, 2016)
Munshiganj	0.1-0.3	mgm^{-3}			(Khalequzzaman et al., 2011)
Chittagong			1447± 665.3	μgm^{-3}	(Kumar et al., 2024)

Rangpur (mud-houses)	25(16-56)	μgm^{-3}	152(71-300)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)
Rangpur (soil-houses)	52(20-115)	μgm^{-3}	129(41-340)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)
Rangpur (tin-shed concrete-houses)	41(18-150)	μgm^{-3}	78(32-135)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)
Rangpur (brick-houses)	46(30-86)	μgm^{-3}	151(71-381)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)
Rangpur (modern-houses)	35(19-53)	μgm^{-3}	92(39-142)	μgm^{-3}	(Md. Mahamudul Hasan, 2025)

2.2 Relationship between the concentrations of particulate matter and the airborne microbiological organism

The relationship between particulates and airborne microbes is an upcoming progenitor field with heaviness for public health, the environment, and atmospheric processes. Fine particulate matter including PM 2.5 and PM 10 not only contributes to air pollution but also carries a healthy share of more than thousands of microorganisms, particularly bacteria, fungi, and viruses. The bioaerosols can also be more extensive, and longer-lived in the atmosphere, and can humanly affect many humans, ecological systems, and atmospheric chemistry¨.

The increase in PM levels in a city is mainly due to increased urbanization, industrialization, and vehicular emissions, especially in densely populated cities. PM-associated microbes have been shown to enhance the health risk, which manifests as respiratory diseases, allergic reactions, and hospital-acquired infections. For example, *Streptococcus pneumoniae* as bacteria and *Aspergillus fumigatus* fungi are very frequently collected from PM surfaces and are implicated in creating a high health hazard. The presence of antibiotic-resistant bacteria and poor sanitation in the polluted environment further complicates the treatment of infections in an environment polluted with airborne particulates. The impact of seasons on microbial load is also evident, as most peaks occur in winter and dust storms, leading to more exposure to health risks in susceptible populations.

Microbes present in PM can affect precipitation and weather patterns through their ability to act as cloud condensation nuclei. These microflora also have some contribution to nutrient cycling and affect the chemical weathering of PM, thus changing its toxicity and persistence in the environment. These very arguments call for a multidisciplinary approach to better understand the wider implications of PM-microbe relationships.

This relationship needs addressing for some important reasons. First, understanding the microbial composition of PM will secure information on health risks, which would eventually allow the development of interventions for effective public health. Second, such knowledge forms the basis for air quality management strategies, guiding policymakers in the mitigation of other effects of chemical and biological pollutants. Thirdly, it borrows lines from urban planning and environmental policy that explain pollution dynamics and consequent ecological effects. Lastly, research in this area could inspire innovative solutions, such as a microbial bioremediation technique to reduce PM toxicity and environmental footprint.

PM and microbial interactions' knowledge of health, environmental sciences, and atmospheric chemistry is extremely important. Researchers could come up with well-targeted interventions to curb health impacts, improve air quality, and promote sustainable environmental mantras by ruling out some of this complex entanglement. In particular, there is an urgent need for such research with respect to urbanization growth and rapid industrial development coupled with climate change that continuously adds to the plight of mankind due to particulate matter and its associated microbes.

2.2.1 Bangladesh case study: particulate matter, a media for airborne microorganisms

The study (Salam et al., 2008) following the five regions of the capital Dhaka of BCIC Bhaban at Motijheel, Tower Bhaban at Dhaka University campus, Medinova Hospital at Dhanmondi, Novelties Pharmaceuticals at Tejgaon and Jahangir Nagar University campus. This study newly characterized the composition of the complex air mixture under the chemical compositions, trace elements, aerosols, and heavy metals.

The study first explained the trace gasses; the atmospheric trace gases (SO_2, NO_2, CO, and O_3) were measured at five locations in Dhaka from January to April 2006. Samples were collected once a week at each location. The sampling time was 8 h for SO_2, NO_2, and O_3 and 1 h for CO. The samples were collected in an impinger attached to the PM samplers for SO_2, NO_2, and O_3, and an organic vapor sampler was used for CO measurements with the Indicator Tube method. The overall average value of SO_2 at five sampling locations in Dhaka was 48 μgm^{-3}, which is very close to the annual average of the World Health Organization's (WHO) guideline values for the European Union (WHO 2000: 50 μgm^{-3}). Because the total sampling period in our study was about 4 months [8 h daily for all gases except CO (1 h)] and extended from the winter through the beginning of the monsoon season, it can be considered to be an average for the whole year. The highest concentration (76.8 μgm^{-3}) of SO_2 was found in the commercial and heavy traffic areas (BCIC Bhaban, Motijheel), and the lowest concentration (20.7 μgm^{-3}) was found in the semi-urban area (Jahangirnagar University campus, Savar). The elevated concentration of SO_2 in the city center is probably due to the high content of sulfur in fossil fuels. Azad and Kitada (1998) reported that the primary source of SO_2 in Dhaka is traffic fuels (55.8%) followed by brickfields (28.8%), industry (10.5%), and others (about 5%); they also reported high SO_2 concentrations in the southern industrial area, where the highest value was about 286 μgm^{-3}. The total average concentration of NO_2 at five locations in Dhaka was 21.0 μgm^{-3}, which is about half of the annual WHO guideline value of 2005 (40 μgm^{-3}). The NO_2 enters the atmosphere from various natural and anthropogenic sources, including lighting the action of microorganisms on nitrogen-based fertilizer, but the most important and major anthropogenic source is the combustion of fossil fuel in traffic. The highest concentration of NO_2 (40 μgm^{-3}) was found at Medinava Hospital, Dhanmondi site, with medium traffic, whereas the lowest concentration (5.0 μgm^{-3}) was found at Jahangirnagar University, Savar, a semi-urban location. Azad and Kitada 1998 measured NO_2 concentrations with molecular diffusion tubes in Dhaka, Bangladesh. They reported that the highest 10-day average was about 65.8 μgm^{-3}, with higher concentrations appearing in the city center along the main roads of Dhaka. Motor vehicles and brickfields were speculated to be the two major emission sources in Dhaka. The measured CO values varied between industrial, urban, and semi-urban sites. The highest concentration (334 μgm^{-3}) of CO was observed at the industrial site (Novartis, Tejgaon), whereas the lowest value (42 μgm^{-3}) was found in the semi-urban area (Jahangirnagar University, Savar). The highest concentration of CO at the industrial sites is presumably due to the incomplete conversion of fossil fuel during different mechanical and industrial processes.

As of the determination of systematic concentrations of particulate matters across the Dhaka area, these elements (PM 10, PM 2.5) were collected on micro-fiber filters with low-volume samplers from 9:00 A.M. to 5:00 P.M. (8 h on average) between January and April 2006 at five locations in Dhaka, Bangladesh. Total suspended particulate matter was calculated from the sum of the PM 10 and particles larger than PM 10 (collected in the dust CupVail). The total average concentration of SPM in the ambient air of Dhaka was 262.6 μgm^{-3}. The World Bank and Department of the Environment of Bangladesh found SMP concentrations of 665–2456 μgm^{-3} at Farmgate, Dhaka based on 8-h measurements at several locations along busy roads in

Dhaka city. The difference between these 1998 results and those of our study indicates that the ambient concentrations of SPM in Dhaka are decreasing remarkably. However, our measurements showed that the maximum daily average (exposure time: 8 h daily) concentration of SPM was 570 μgm^{-3} at Motijheel in January 2006. The SPM concentrations among the five sampling sites varied from 126.2 μgm^{-3} at Jahangirnagar University (JU) campus, Savar to 523.0 μgm^{-3} at BCIC Bhaban, Motijheel. The causes of the higher SPM values in Dhaka may be road dust, construction activities, incomplete combustion of fossil fuel from traffic vehicles and brick kilns, and long-range transport. The total average concentrations of PM 10 and PM 2.5 were 75.5 and 66.2 μgm^{-3}, respectively, at five locations in the greater Dhaka area. At the five sampling locations in Dhaka, the average mass concentrations varied from 62.0 to 91.2 μgm^{-3} for PM 10, whereas these ranged between 54.2 and 80.5 μgm^{-3} for PM 2.5.

Furthermore, Dhaka city's particulate matter was found to be heavy metals. The concentrations of selected trace metals were determined at five locations in the greater Dhaka region for PM 2.5 in the period from January to April 2006. PM 2.5 samples were collected on fiber filters (diameter 4.7cm) with a low-volume sampler. An AAS was used to determine the concentrations of heavy metals (As, Cd, Cu, Fe, Pb, Zn).

Atmospheric pollution at five locations in greater Dhaka, Bangladesh, was characterized in terms of trace gases, PM, and heavy metals. The average concentration of O_3 in the greater Dhaka area was lower than the WHO guidelines value (WHO 2005). Elevated concentrations of PM were observed in Dhaka, but these were still lower than those reported for Southeast Asian sites. Particulate mass originates mostly from fine particles (about 88% of PM10 mass was from PM 2.5). The concentrations of Pb, Zn, Cu, Fe, As, and Cd were much lower than the previous measurements in Dhaka city. In particular, the Pb concentration is decreasing due to the ban on leaded fuel in Bangladesh.

The association and correlation between particulate matter and air microbiomes serve as critical and significant parameters in understanding possible health risks to public health and environmental dynamics. Airborne particulate matter is collected to be corresponding vehicles of different kinds of heterogeneous microbial populations, including pathogenic bacteria, in user areas such as Dhaka. These microbes attach to particulate matter and travel far with increased human exposure to potentially harmful organisms.

Dhaka the capital of Bangladesh, is one of the leading areas in the world causing severe PM pollution. Following the extreme particulate matter pollution, a study (Nawar et al., 2021) ascertained the enumeration of the prevalence of the microorganisms present in the air of Dhaka city to get an idea of the pathogenic bacteria present in such an extremely polluted area. Following Dhaka’s urban environment, the air samples were collected from seven locations. Air samples were collected by applying the plate sedimentation technique for microbiological analysis. As for the results, the air sample collection zones were chosen to cover the most important and crowded areas of Dhaka city. Eight pathogens were found, which reveal early signs of being potential health hazards to the environment. The study clarified that these proven pathogens are found in the air and some of them resist a number of commonly used antibiotics and people are highly exposed to it. Mutated characteristics might be present among all of the eight microbes for which whole-genome sequencing is a must to find out the mutation in the strain. The virulence activity of pathogens could be detected too along with its course of transmission.

Based on studies in the city of Dhaka show that cities can have a high concentration of pm because some of them contain a very high antibiotic-resistant bacteria population. These microbes, when inhaled directly into the lungs, may lead to respiratory diseases, systemic disease conditions, or aggravate chronic health problems. Some strains of microbes on pm have further undergone genetic mutations that have increased their pathogenicity and resistance to commonly used antibiotics, thus increasing the burden on any treatment method used by medical institutions to treat these cases.

2.2.2 International setting: particulate matter, a media for airborne microorganisms

A study (Alghamdi et al., 2014) systematically determined the association of microorganisms with particulate matter following the urban air of Jeddah, Saudi Arabia. Through five months of systematic research, the microbiological quantity was investigated in the particulate matter along with the influential meteorological factors. As for the outdoor environment, PM 2.5 concentrations were assessed in a range of 13.6 to 211.4 μgm^{-3} with an average of 60 μgm^{-3}, whereas the PM 10 concentration was achieved in a range of 61.2 to 216.3 μgm^{-3} with an average of 159.9 μgm^{-3}. As for the microorganisms, Fungi and actinobacteria-associated particulate matter were identified as having lower concentrations than bacteria. As another result, the sum of the microbial loads was higher in PM 10 than the PM 2.5. Alternatively, a significant correlation was found for the sum of the microbial loads associated with PM 10 and PM 2.5. While looking at the Fungi, *Aspergillus fumigatus* and *Aspergillus niger* were newly identified as the very common fungal types associated with the particulate matter. The microbes were measured as: Bacteria, 45-591 CFUm-3; Fungi, 4-28 CFUm-3; Actinobacteria, 1-16 CFUm-3. As for the influential factors for the variability of the microbes, temperature, wind speed, and the presence of the pollutants were determined. Temperature negatively impacted the association between the microorganisms with PM 2.5. The key determinants included the wind speed and inverse PM 2.5 concentrations. As of the conclusion of this study, the obtained concentrations of microorganisms that were associated with particulate matter were low, and a significant correlation was not achieved with the mass concentrations of particulate matter. The determined concentrations of the microorganisms that were associated with the particulate matter varied with the influence of the very complex dynamics of weather conditions and air pollutants. Temperature was positively correlated with particulate matter mass concentrations, and wind speed was found to accelerate the survival of airborne microorganisms and help the dilution of particulate matter. The reason why the microorganisms associated with the particulate matter are low is that the outdoor microbial sources of soil, plant litter phylloplane, composts, wastewater treatment plants, and animal faces are rare. A positive correlation (r=0.23) and negative correlation (r=-0.2) were obtained in this study between the bacterial and fungal concentrations related to PM10 and PM 2.5, respectively. The related Bacteria with particulate matter concentrations were found to be highly variable due to the attribution of the influence of anthropogenic activities and atmospheric changes. As the environmental/meteorological parameters, the wind speed positively correlated with microorganisms associated with PM 2.5 and PM 10. Temperature presented significant positive correlations with the mass concentration of PM 10 (r=0.44) and PM 2.5 (r=0.5).

A study (Che et al., 2021) investigated the influence of fine particulate matter and atmospheric microorganisms on the pulmonary microecology of COPD patients in northeast China. Overall, the increase in the concentrations of atmospheric fine particles increased the diversity and abundance of bacteria in the collected human samples for the COPD patients. The outdoor PM 2.5 concentrations were reported as higher levels, which provided potential associations with the microorganism exposures. The pathogenic microbes seemed to be more prevalent during higher PM 2.5 periods. The key contributors compost of *Streptococcus* and *Mycoplasm*a. The mechanism causing COPD is that the microbes carried by PM 2.5 were likely to contribute to airway remodeling and disease progression.

A study (Shammi et al., 2021) focused on bioaerosols in association with particulate matter mainly based on the Asian megacities. The quantity and the load of microbial bioaerosols and their environmental characteristics are governed by air pollution, such as haze, fog, dust, and particulate matter, and it significantly affects the air quality index. The urban factors and human factors of the heavy traffic, overcrowds, and burning of biomass were found to be influenced by the prevalence of the atmospheric bioaerosol generation mechanism. In the case of bacterial bioaerosols, the highest amount of bacterial abundance, rates, and relative bacterial contributions to the total aerosol loads were found to be observed in the seasons of autumn and spring. The bacterial cells presented a foremost fraction of the overall variation of particulate concentrations of the near-surface aerosol particles greater than 0.5 micrometers. Among the Fungal Bioaerosols and Spores, the meteorological parameters tremendously controlled their loads in the atmosphere, including the ambient temperature, humidity, precipitation, wind directions, and speeds. The diurnal variability and the presence of the haze days greatly affected the mycological population in the PM 2.5 samples. Moreover, in the case of the Viruses, the ambient particulate matter in the polluted air interacts with the viral aerosol and alters their infectivity. Due to the extensive urbanization across Asia, the particulate matter increased significantly, which contributed to the abundance of bioaerosols during the hazy and foggy days, along with the aerodynamics controlling their floating behavior. Furthermore, the urban vehicles and uncontrolled burning situations further regulated the prevalence of bioaerosols in the diverse concentrations in the outdoor air and finally transmitted to humans. As a consequence, the pathogenic bioaerosols in the outdoor air often accelerate allergens and respiratory diseases among children and adults.

Based on the hospital environment pertaining to the relationship between particulate matter and airborne microorganisms, a study (Hiwar et al., 2021) systematically ascertained the relationship. Using the meta-analysis review framework, this study found that the estimated concentration of airborne microbes as the aerobic colony count was significantly associated with the particle mass concentrations, with a positive correlation of 0.4. While investigating the environmental parameters, they seemed to be related to the generating source, survival, dispersion, and deposition rate of microorganisms. As the factor of the generation as well as the deposition on the hospital environments from the microorganism, foot traffic was newly identified. In the hospital environment, the airborne microorganism concentration presented a weak positive correlation with the temperature. In the case of relative humidity, it was not significantly correlated with the hospital's airborne microbial organisms. On the other hand, in the case of the particulate matter, a moderately significant correlation was obtained between the airborne microbes and the particle concentrations. The airborne microorganism ranged from 378 to 3000 cfum^{-3}, while the particle mass particle mass ≤5 μg [5– 61 μgm^{-3}], and >5 μg [18.8– 188 μgm^{-3}] were obtained. In the hospital environment ascertaining the relationship, a relatively small number of studies focused. It is noted that the majority of the studies were based on bacteria and fungi; so far, no studies have investigated sufficient data for the correlation between viruses and indoor air quality in hospital settings.

In a study (Cao et al., 2014) followed by a severe smog event in China, the inhalable microorganism was investigated in PM 2.5 and PM 10. As for the potential exposure of humans, especially to allergies and respiratory diseases from microorganisms present in Beijing 's air, this research focused on the January session when severe air pollution events occurred. As of the results, the foremost inhalable microorganisms were identified as the soil associated, and these are nonpathogenic to humans. Moreover, microbial allergens and pathogens were determined to possess their relative abundance and were found to increase as of the increase of particulate matter pollution. The study identified the bacterial, archaeal, fungal, and dsDNA viral species in the collected particulate matter samples. The particulate matter pollution was achieved to be higher in winter. However, the low temperature correlated with lower microbial abundance in this season compared to the warmer seasons.

A study (Mazlan et al., 2021) in Malaysia used the farming industry to investigate the relationship between particulate matter and airborne microorganisms. As of the concrete result, any of the changes of the particulate matter affected the airborne microorganism pollution. As the results in this study, the concentration of PM 2.5 presented mean values for pens A, C, D, and E were 55.38 mgm^{-3}, 61.0225 mgm^{-3}, 45.76 $mgm^{-3,}$ and 57.67 mgm^{-3} respectively. The PM10 showed mean values for pens A, C, D, and E were 79.04 mgm^{-3}, 87.18 mgm^{-3}, 65.38 $mgm^{-3,}$ and 82.4 mgm^{-3}. Alternatively, the airborne microbes showed mean values for pens A, C, D and E were 22.21 cfu × 103/m3, 54.26 cfu ×103 m^{-3}, 13.38 cfu × 103 m^{-3} and 39.53 cfu × 103 m^{-3}. The factor analysis for parameter concentrations was identified as the number of goats, the height of the pen building, the activity across the pen, and the environmental parameters of temperature and humidity. The correlation analysis expressed the R2 values between PM 2.5 and airborne microorganisms as around 0.6 and for PM 10 0.7. Thus, a significant correlation was obtained in this research.

Following the composition, deeper characteristics, and factor analysis, a study (Zhai et al., 2018) ascertained the relationship between airborne microorganisms and particulate matter. The influential mechanism between airborne microorganisms and particulate matter is still ill-defined. The foremost research works conducted on this topic are mainly the measurement of temporary relationships under particular circumstances.

A study (Miri et al., 2023) was conducted to ascertain the meteorological impact of air pollutants on bacterial concentrations in the urban areas of Iran. The bacterial concentration presented a decreasing trend from summer to winter, which coincided with a decreasing pattern of air pollutant indices. The potential and foremost factors that affected the bacterial concentration identified in this research are PM10, wind speed, relative humidity, and atmospheric temperature. Both the air pollutants of PM 2.5 and PM 10 were found to be better related to the bacterial concentrations than the meteorological parameters in the investigated areas. Among the meteorological settings, wind speed, temperature, and relative humidity were identified in this research work.

3. Discussion

Ultimately, this study focused on three main aims throughout the thesis paper: firstly, reviewing the systematic status of particulate matter pollution across Bangladesh, the potential association with airborne microorganisms using a Bangladeshi case study, and finally, ascertaining the relationship using the international perspective. As of the preliminary findings of this study as described above sections, a preliminary novel table following the potential particulate matter based Bangladeshi papers has been prepared. This table presents the distinct concentration levels of both PM 2.5 and PM 10 for different regions mainly classified by the urban and rural types, indoor and outdoor based levels, and dwelling type-based exposure levels. Almost all of the results are relatively elevated and thus alarming for the Bangladeshi population. It is noted that in Bangladesh, there is still a lack of peer-reviewed papers in this field; this future review using this study as a reference will be helpful in determining both the dynamics and population-based exposure for Bangladesh. While looking at airborne microbiological elements associated with Bangladeshi particulate matter, significantly limited study was found in Bangladesh. Bacteria and pathogens, especially in the crowded area of Dhaka, were identified in Bangladesh. However, while looking at international settings, especially in Asian countries, microorganisms associated with particulate matter were identified for urban or rural air, hospital settings, farming settings, weather-based dynamic settings, extremely air-polluted environments, biologically exposed people case studies, and agricultural settings. These scenarios definitely can be seen in Bangladesh too; thus, considering this study's findings, new research pertaining to the relationship between airborne microorganisms and particulate matter pollution should be taken into action. Finally, this study is one of the bridges for airborne microorganisms and air pollutants. However, there is still a gap due to lacking this study. Thus, this study is still very preliminary in this important field.

4. Conclusion

Based on the potential human exposure from the particulate matter and the airborne microbiological organism, this thesis primarily reviewed the countrywide particulate matter exposures in Bangladeshi locations, summarized Bangladeshi papers associating the particulate matter-induced microbiological organism, and finally ascertained the international case studies with these relationships. As for the results, almost all of the investigated papers indicated elevated levels of particulate matter in Bangladeshi regions compared to local and international standards. This thesis prepared a novel preliminary table using the relevant data on particulate matters in different locations and settings in Bangladesh. Dhaka and the nearest regions, Chittagong, Savar, and Rangpur, presented the highest levels in Bangladesh, potentially due to the urban environment. This study also analyzed the indoor data, which is new in Bangladesh, expressing the regions of Dhaka and Rangpur with elevated levels of both PM 2.5 and PM 10 concentrations. While looking at the rural area, the dwelling types were found to be the influential factors for levels of the distribution and levels of the particulate matter. In the Bangladeshi region of Dhaka city, the microorganisms of the bacteria were achieved in the area with elevated particulate matter. In the crowded area, eight pathogens were achieved in Dhaka city air. It is noted that there is very limited study in Bangladeshi characterizing the correlations. While looking at the international settings, a potentially significant relationship was obtained between the concentrations of particulate matter and airborne microbes. The Saudi Arabian study ascertained the fungi and antibacterial-associated particulate matter along with meteorological factors of temperature, wind speed, and anthropogenic activities. In the hospital setting, a moderately significant correlation was obtained between the airborne microbes and the particle concentrations. A case study from Beijing, China, during a severe smog event, undoubtedly ascertained the potential relationship between the microbial allergens and pathogens, whose relative abundance has increased with the increase of particulate matter;

however, the inhalable microorganisms were found to be soil-associated and non-pathogenic to human. The animal farming settings in Malaysia expressed that any of the changes in the particulate matter would affect the airborne microorganism population. The influential mechanism between airborne microorganisms and particulate matter is still ill-defined. The foremost research work conducted on this topic are mainly the measurement of temporary relationships under particular circumstances. Thus, based on the measurement sites and the type of settings (i.e., urban air, hospital or animal farm), the severity of the relation was dependent. Thus, the collected information of this thesis for the Asian countries/environment will also be helpful for Bangladesh as the environmental scenarios for the particulate matter mechanism are identical in Bangladesh.

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