Advances in Environmental Technology 4 (2020) 195-209

Iranian Reasearch Organization for Science and Technology (IROST)

Advances in Environmental Technology

Journal home page: https://aet.irost.ir/

Seasonal variations of gaseous air pollutants (SO_2, NO_2, O_3, CO) and particulates ($PM_{2.5}$, PM_{10}) in Gazipur: an industrial city in Bangladesh

Tarmina Akhtar Mukta[1], Mir Md. Mozammal Hoque*[1], Md. Eusuf Sarker[1], Md. Nuralam Hossain[2], Gautom Kumar Biswas[3]

[1]*Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh*

[2]*School of Environment and Ecology, Chongqing University, Chongqing, China*

[3]*Department of Environmental Technology, Jhenaidah Polytechnic Institute, Bangladesh*

ARTICLE INFO

Article history:
Received 23 April 2021
Received in revised form 8 July 2021
Accepted 12 July 2021

Keywords:
Gaseous air pollutants
Particulates
O_3
$PM_{2.5}$
PM_{10}
Wind rose
Air quality index

ABSTRACT

The present study assessed the impacts of seasonal variation on the atmospheric abundance of gaseous air pollutants (SO_2, NO_2, O_3, CO) and particulates ($PM_{2.5}$ and PM_{10}) at Gazipur city. The air pollution data was collected from the study area using a Continuous Air Monitoring Station (CAMS) (CAMS-4, Gazipur) of DoE from October 2017 to September 2018. The highest concentrations of air pollutants were found in the winter ($PM_{2.5}$=208 μg/m^3, PM_{10}=300 μg/m^3, NO_2=45.1 ppb, CO=3.91 ppm, O_3=4.17 ppb) as opposed to those of the post-monsoon ($PM_{2.5}$=133μg/m^3, PM_{10}=169 μg/m^3, NO_2=23.52 ppb, CO=2.25 ppm, O_3=7.71 ppb), pre-monsoon ($PM_{2.5}$=115 μg/m^3, PM_{10}=216 μg/m^3, NO_2=33.5 ppb, CO=1.75 ppm, O_3=4.23 ppb), and monsoon ($PM_{2.5}$=37.5 μg/m^3, PM_{10}=85.6 μg/m^3, NO_2=13.9 ppb, CO=0.84 ppm, O_3=4.23 ppb). The highest concentration of five air pollutants (PM_{10}, $PM_{2.5}$, NO_2, CO, O_3) indicated that the higher pollutant load in the winter was associated with large-scale polluted air transported from the brick kiln at a distance of 5-7 km at the sampling site. The wind-rose data analysis indicated that most of the air during the winter season came to the sampling site from the northern part of the Gazipur district, from the brickfield zones. In contrast, a reverse relationship between the rainfall and atmospheric pollution, temperature, and atmospheric pollution load was observed during the pre-monsoon, monsoon, post-monsoon, and winter. This finding revealed that the lowest concentration of air pollutants during monsoon was associated with the washout effect of precipitation on atmospheric pollutants. A moderate correlation (R^2=0.58) between CO and O_3 pollutants during the study indicated their atmospheric origin by photochemical reactions was associated with volatile organic compounds (VOCs). $PM_{2.5}$ showed a positive correlation with PM_{10} (R^2=0.84),

*Corresponding author.
E-mail: huqmbstu@gmail.com
DOI: 10.22104/AET.2021.4890.1320

indicating that both $PM_{2.5}$ and PM_{10} were produced from similar pathways of fossil fuel combustion by automobiles and industrial activities. Further, the air quality index (AQI) analysis showed unhealthy atmospheric conditions throughout the year for city dwellers around the study area.

1. Introduction

Air pollution is known to have a number of negative consequences on human health and is a major concern for the international community. Globally, air pollution is responsible for 9% of lung cancer deaths, 17% of chronic obstructive pulmonary disease deaths, more than 30% of ischemic heart disease and stroke deaths, and 9% of respiratory infection deaths. According to the World Health Organization (WHO), ambient air pollution caused approximately seven million fatalities in 2012, accounting for more than 10% of all-cause deaths and more than double the earlier estimates [1,2]. Air pollution may be defined as any atmospheric condition in which certain substances exist in such concentrations to produce undesirable effects on both humans and the ecosystem [3]. Moreover, 'substances' refers to any natural or manmade chemical elements or compounds capable of being airborne. These may exist in the atmosphere as gases, liquid drops, or solid particles. Air quality has deteriorated due to both human activities and natural phenomena such as windblown dust particles. There are two significant sources of air pollution in Bangladesh: vehicular emissions and industrial emissions. However, these are mainly concentrated in major cities. Recently, air pollution has received significant attention among the contemporary environmental issues in Asia and other parts of the world. Exposure to air pollution is the leading environmental threat to human health in many towns and cities. Particulate emission is mainly responsible for increased death rates and respiratory problems for the urban population. Air pollution is one of the most serious environmental issues in many developing countries [4]. It is important to assess the impact of air pollution in urban cities. More than 80% of people worldwide who live in urban areas are exposed to air quality levels that exceed WHO acceptable limits [5]. Atmospheric pollution in urban areas is a significant concern in many developing countries around the world. Sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) are important primary pollutants in the ambient air because of their adverse effects on human health and vegetation and their contributions to the acidification of the environment [6]. The oxides of nitrogen (NO_x) play a role in the formation of photochemical oxidants; NO_2 contributes to the buildup of tropospheric ozone (O_3) and the lifetime of greenhouse gases [7]. Particulate air pollution can be generated by natural and anthropogenic activities such as stationary and mobile sources. It has been estimated that traffic-related emissions constitute more than 50% of the total particulate air pollution [8]. Particulate matter pollution is a significant issue in the large cities of Bangladesh. The main contributors of air pollution are motor vehicles, brick kilns, diesel generators, and industries. In recent years, much research interest has been shown to atmospheric particles as they influence climate change and cause adverse health effects. Ambient air pollution is a complex mixture of particles and gaseous pollutants [9]. The pollutant species in Bangladesh concerning transportation systems are carbon monoxide (CO), hydrocarbons (HC), photochemical oxidants, e.g., ozone (O_3), nitrogen oxides (NO_x), suspended particulate matter (SPM), sulfur dioxide (SO_2), and lead (Pb). Air quality monitoring data is limited in Bangladesh. However, periodic surveys by the Department of Environment (D_OE) indicate that the ambient levels of SPM, SO_2, and airborne lead are higher than the Bangladesh air quality guidelines. The pollutants emitted from automobiles are an apparent contributor to the pollution problem in Bangladesh; however, no emissions inventory detailing the sources of pollution at the national level is currently available [10]. Recently, the World Health Organization air quality model confirms that 92% of the world's population lives in places where air quality levels exceed WHO limits and three million people die every year from outdoor air pollution [11]. Despite improvements in air quality in some regions, global outdoor air pollution levels have increased by 8%

from 2008 to 2013 [12]. The Clean Air Act requires the United States Environmental Protection Agency (EPA) to set limits for six common air pollutants (also known as "criteria air pollutants") [13]. They can harm human health and the environment and cause property damage. Breathing ground-level ozone can result in several health effects observed in broad segments of the population, including the induction of respiratory symptoms, decreased lung function, and airway inflammation, including chest tightness and wheezing [14]. In recent years, air pollution, especially fine particulate matter ($PM_{2.5}$), has become a serious environmental problem in 45 of China's economically well-developed regions [15]. A study also reported that the air quality in Chittagong city was very harmful and negatively affected the native residents [33]. Although most recent attention has focused on reducing carbon dioxide (CO_2) emissions due to concerns about global climate change, local air pollution is still a critical issue that poses an acute threat to both public health and natural ecosystems [16]. To the best of our knowledge, past research lacks information on the emitting sources of air pollutants, their transformation processes, and seasonal fluctuations in air pollutants. Unplanned urbanization without considering the geological aspects has brought significant changes in the geo-environment of Gazipur city. Population growth, waterlogging, industrial pollution, changes in the hydrogeological system, localized land subsidence, and building collapse are the hazards of these changes in the geo-environment. Gazipur city is confronted with significantly high physical growth and an increase in the population [17]. Therefore, it is undoubtedly important to examine the relationship between seasonality and increasing emission rate to determine its consequences in the future. Gazipur is selected for this study because of its rapid urban and industrial growth. This study helps the general public, stakeholders, researchers, planners, and policymakers develop effective air pollution abatement strategies and implement urban planning. Therefore, the present study aims to determine the air quality status in Gazipur city, identify the emitting source of air pollutants and their transformation pathways, and find the seasonal variations (pre-monsoon, monsoon, post-monsoon, winter) of air pollutants.

2. Materials and methods

2.1. Study area

The study was conducted in the city of Gazipur (Figure 1), situated at the latitude 23.99° N and longitude 90.42° E in the middle part of Bangladesh. The city is congested with aging, highly polluting vehicles. Many small-scale factories are also found in the town. Moreover, the construction of highways and buildings takes place continuously throughout the city. The high influx of people from rural areas, poorly maintained emissions from various kinds of motor vehicles, and biomass/coal burning creates a huge amount of dust load in the city air [18]. This location is also characterized as a traffic area because many vehicles enter Dhaka city through Gazipur city from the northern part of the country, and a large number of industries are situated in Gazipur. The CAMS site is located about 200 meters away from the main road. The roof height is about 7 m above the ground, and the intake nozzle of the sampler is located 1.8 m above the roof [18]. CAMS-4 (Gazipur) is considered a hot spot site due to the proximity of several major roadway intersections and the large numbers of vehicles plying through this area.

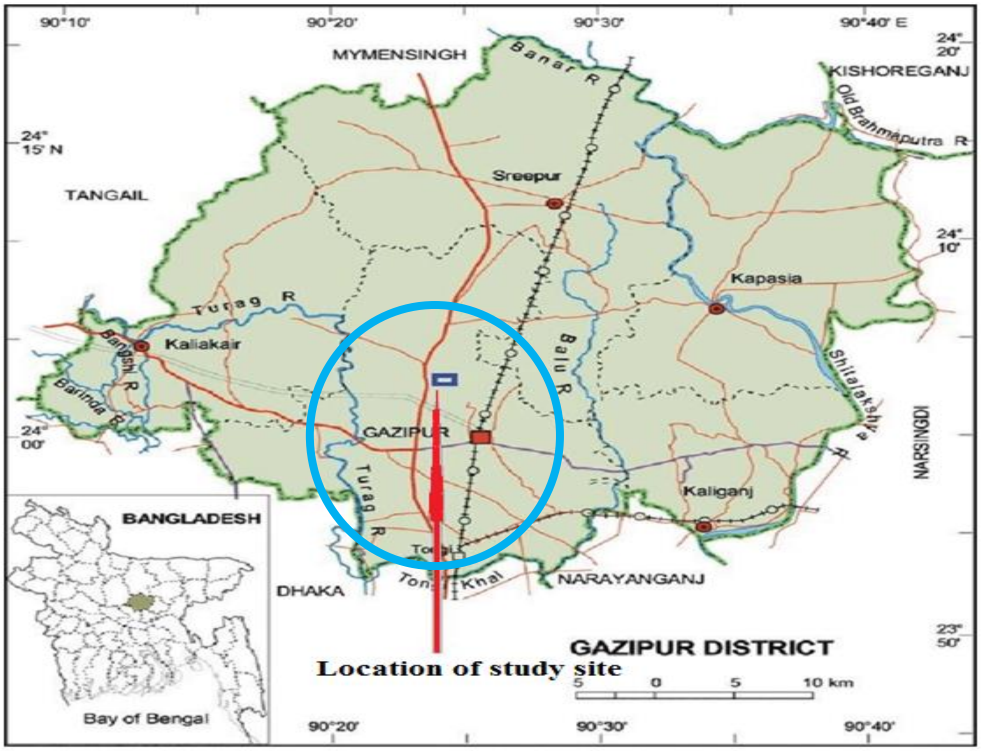

Fig.1. Map of the study area of Gazipur city.

2.2. Data collection

Measurements of trace gases were done in a continuous air monitoring station (CAMS) near the Gazipur area (latitude 23.99° N; longitude 90.42° E) from October 2017 to September 2018. This location is also characterized as high traffic because a large number of vehicles move around Gazipur city. Air pollution data on PM_{10}, $PM_{2.5}$, NO_2, NO_2, SO_2, CO, and O_3 levels were collected from secondary sources at a single point/location base from Gazipur (CAMS-4). Statistical analysis software (SAS) was used to determine the significant levels of air pollution in the study area.

2.3. Methods of analyzers

The four gas analyzers used at CAMS were sulfur dioxide (SO_2) analyzer, carbon monoxide (CO) analyzer, nitrogen oxides (NO_2) analyzer, and ozone (O_3) analyzer. They continuously measured the concentration of SO_2, CO, NO_2, and O_3 present in the ambient air. A number of commercial instruments were used for the continuous measurement of trace gases. O_3 was observed with a UV photometric analyzer (Teledyne Monitor Labs (TML), Inc., model 9810B). CO was measured using a non-dispersive infrared spectrometer (TML, model 9830 B). NO, NO_2, and NOx were measured using a chemiluminescence analyzer (TML, model 9841 B); SO_2 was measured using a pulsed UV fluorescence analyzer (TML, model 9850 B). All instruments were housed in an air-conditioned room. A time-to-time calibration was performed, whereas all calibration processes were traceable to the National Institute of Standards and Technology (NIST) standard.

2.4. Statistical analysis

The data were coded and tabulated into an excel sheet (Excel 2016). After the completion of data entry, the data were cleaned through frequency analysis by finding the outliers. The data were carefully cleaned and validated to increase reliability. The chemical analysis of the soil samples was done with the help of a scientific calculator. All the local units were converted into standard units. Various statistical analyses were performed via SPSS software (Version 20.0).

3. Results and discussion

3.1. Ambient air quality and seasonal variation in Gazipur city

Table 1 shows the seasonal variability of six air pollutants (SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10}) from the study area. As shown in Table 1, all of the pollutants, including gaseous and particulates, show the highest concentration in winter except SO_2 and O_3, followed by the post-monsoon, pre-monsoon, and monsoon seasons.

3.1.1. Seasonal variation of $PM_{2.5}$

Figure 2 shows the post-monsoon (October and November), winter (December to February), pre-monsoon (March to May), and monsoon (June to September) seasonal variations of $PM_{2.5}$ concentration of Gazipur city. Figure 2 shows increasing trends of $PM_{2.5}$ from October 2017 to January 2018, and after that, it decreases from February 2017 to September 2018. During the observations, the highest value of $PM_{2.5}$ (208 µg/m^3) was found in January 2018, and the lowest value of $PM_{2.5}$ (28 µg/m^3) was measured in July 2018. The maximum and minimum concentrations of $PM_{2.5}$ were found as 231.5 µg/m^3 on December 12, 2013, and 80.9µg/m3 on January 10, 2014, respectively [22]. Moreover, the standard annual value of $PM_{2.5}$ in Bangladesh is 15 µg/m (19]. However, the average value (94.43 µg/m^3) of $PM_{2.5}$ in the current study is six times higher than those of the annual Bangladeshi standards [19]. It may happen because many brick kilns are situated 5-7 km north of the Gazipur sampling site (Figure 1) However, over the past decade, $PM_{2.5}$ concentrations exceeded the national standards during the dry season while remaining somewhat below the standards during the rainy season [20]. Moreover, wintertime $PM_{2.5}$ maximum concentration was associated with enhanced atmospheric emissions from fossil fuel combustion, biomass burning, and unfavorable meteorological conditions for pollution dispersion.

Table 1. Seasonal concentrations (avg.) of SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10} in the study area.

Season	Pollutant concentration					
	$PM_{2.5}$ (µg /m^3)	PM_{10} (µg /m^3)	SO_2 (ppb)	NO_2 (ppb)	O_3 (ppb)	CO (ppm)
Post-monsoon	132	132	4.0	21	7.0	1.4
Winter	171	266	1.9	42	4.0	2.4
Pre-monsoon	74.2	131	5.3	16.3	4.0	1.7
Monsoon	32.5	61.4	8.4	8.1	2.9	0.7

3.1.2. Seasonal variation of PM_{10}

During the observations, the highest value of PM_{10} (300 µg/m^3) was found in January 2018, and the lowest value of PM_{10} (50.79 µg/m^3) was measured in August 2018 (Figure 3). Bangladesh's national standard value of PM_{10} is ~10 times higher than that (141.80 µg/m^3) of the current study [19]. Similarly, the highest concentration of PM_{10} was found in the winter at Andhra Pradesh [21], and the maximum concentration of PM_{10} was found in Gazipur city on January 8, 2014 [22]. This pollutant level exceeded the average standard due to diesel-driven trucks, vans, pickups, motorized vehicles, and brick kilns operating in the winter [22].

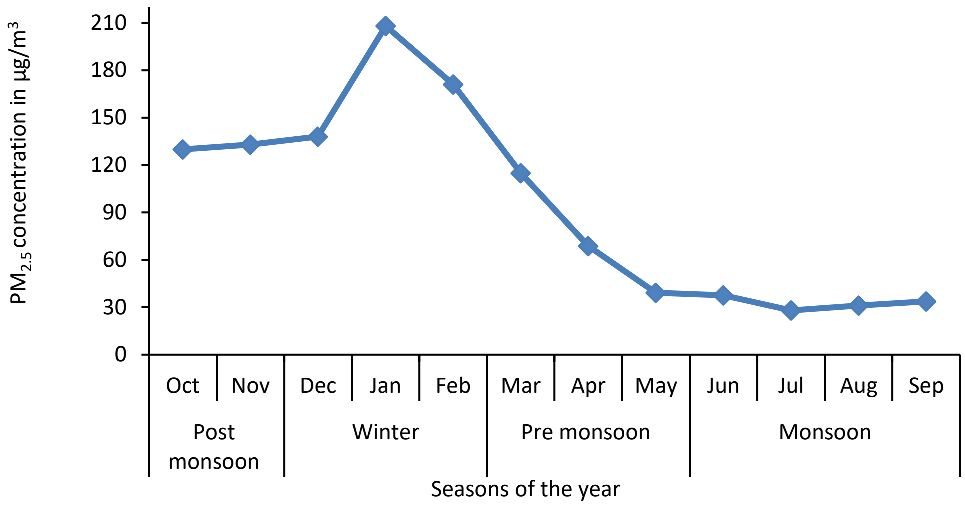

Fig.2. Seasonal variation of $PM_{2.5}$ concentration in Gazipur city.

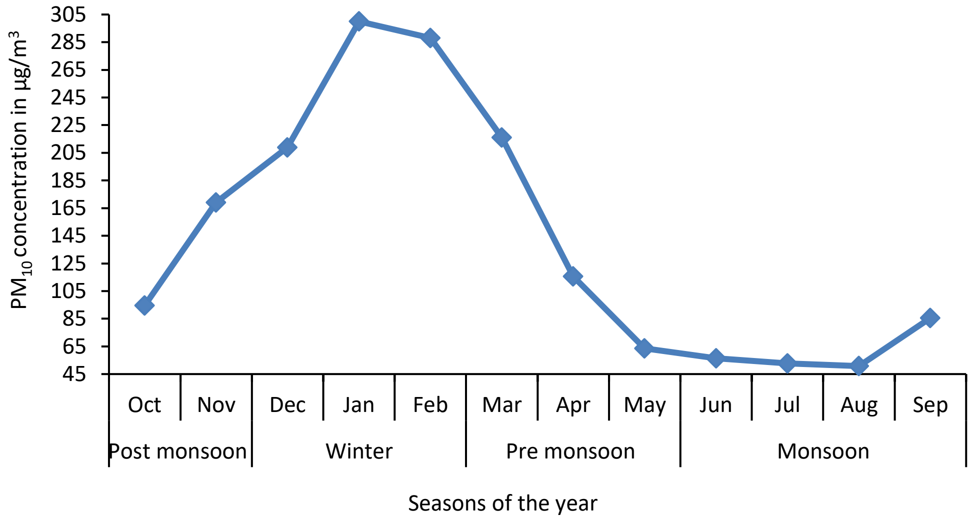

Fig.3. Seasonal variation of PM_{10} concentration in Gazipur city.

3.1.3. Seasonal variation of SO_2

As shown in Figure 4, the SO_2 concentration of the study area shows increasing trends from October to November and May to July. The lowest concentration of SO_2 (1.40 ppb) was measured in December 2017, and the highest concentration of SO_2 (15.9 ppb) was in July 2018. Similar studies were observed in Gazipur city [22] and Andhra Pradesh [21]. The highest peak of SO_2 in the dry season and the base concentration in the wet season may occur since their emission sources are associated with motor vehicles, brickfields [23], and industry [24,25]. Interestingly, the concentration of SO_2 was 19.08 times lower than the annual national standard [19].

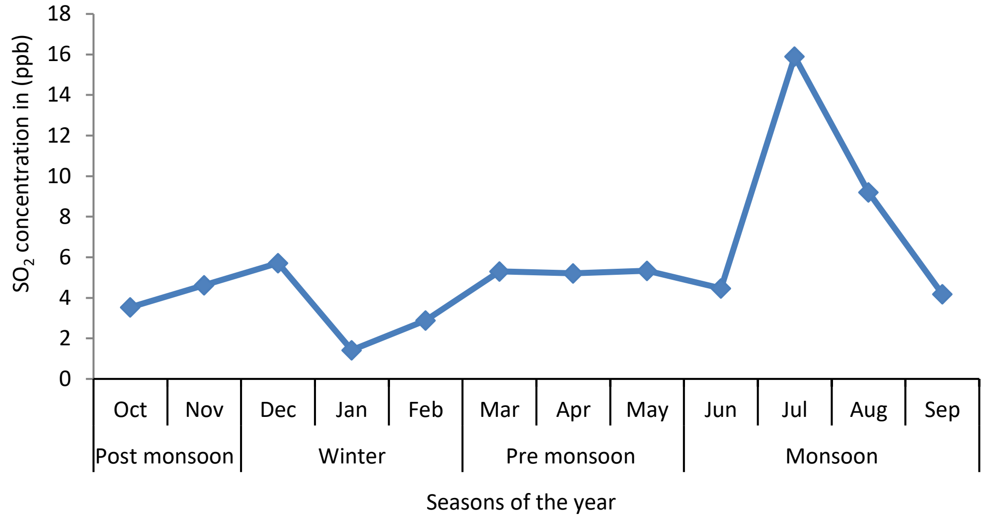

Fig.4. Seasonal variation of SO_2 concentration in Gazipur city.

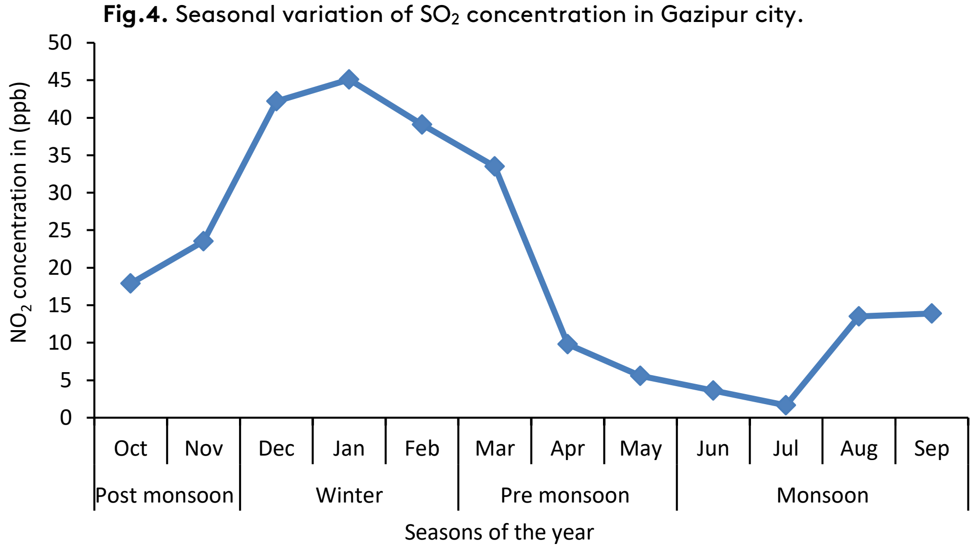

Fig.5. Seasonal variation of NO_2 concentration in Gazipur city.

3.1.4. Seasonal variation of NO_2

Figure 5 shows the seasonal variations of NO_2 concentration in the ambient environment of Gazipur city from October 2017 to September 2018. The highest concentration of NO_2 (42.17 ppb) was measured in the winter season (December-February), 2017, and the lowest concentration (8.17 ppb) during the monsoon season, 2018. Similar studies reported that the highest NO_2 was found in the winter season [21,23]. A significant concentration of NO_2 was found over Bangladesh during the dry season (November-March) [26]. NO_2 emissions are produced primarily from fossil fuel burned in motor vehicle engines, power plants, industrial boilers, and emissions from aircraft, vehicles, and other equipment [27].

3.1.5. Seasonal variation of O_3

The highest concentration of O_3 (4.03 ppb) was measured in the winter season, 2017, and the lowest value (1.53 ppb) during August (Figure 6). After the highest peak of O_3 concentration (winter, 2018), this figure shows decreasing trends and reached the lowest concentration (2.92 ppb) during monsoon season, 2018. The maximal monthly O_3 concentrations in the winter of 2002, 2003, 2004, and 2005 were 41 ppb, 60 ppb, 60 ppb, and 59 ppb, respectively [23]. The Bangladesh standard value of O_3 is 17.81 times higher than the average annual value (4.49 ppb) of the current study [19].

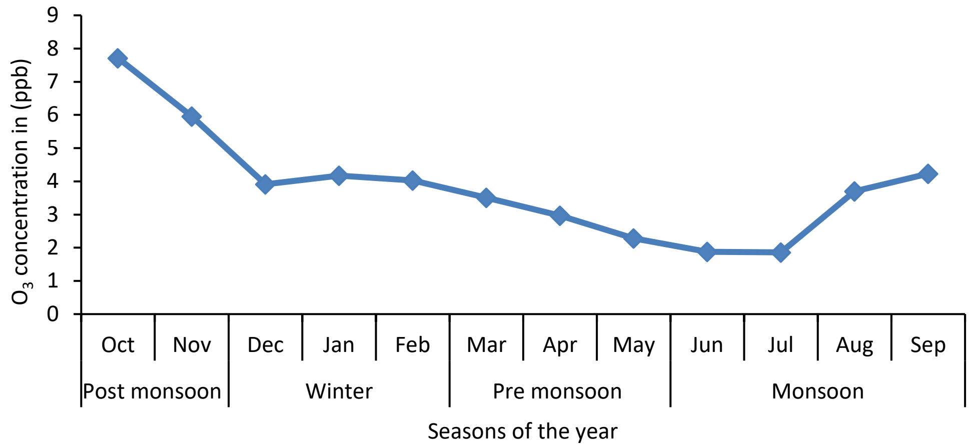

Fig.6. Seasonal variation of O_3 concentration in Gazipur city.

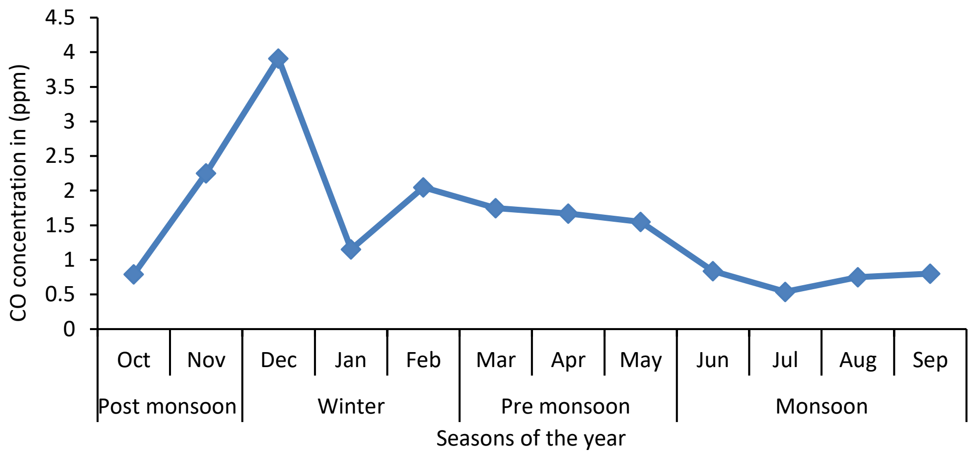

Fig.7. Seasonal variation of CO concentration in Gazipur city.

3.1.6. Seasonal variation of CO

Figure 7 shows that the highest CO (2.37 ppm) concentration was measured in the winter season, 2017, and the lowest concentration (0.73 ppm) during the monsoon season, 2018. Similarly, the seasonal cycle of CO had a high peak in the winter and base in the summer season [23]. Seasonal variations with maximum concentrations of CO in the winter period and minimum concentrations in the summer period are observed in Kuwait [28] and Japan [29]. These CO trends may be attributed to the emission of different industrial sources and the many vehicles circulating in the Dhaka metropolitan area. Some meteorological factors such as weaker wind speed and lower height of the mixing layer during the winter season indicate a high CO peak.

3.2. Relationship between $PM_{2.5}$ and rainfall

Precipitation can effectively decrease $PM_{2.5}$ mass concentrations through a wet deposition [32]. Precipitation can effectively remove atmospheric particulate matters, especially those that are smaller in size. Figure 8 indicates that the relation between $PM_{2.5}$ and rainfall is negative. $PM_{2.5}$ shows an increasing trend in the post-monsoon (October-November) and winter (December-February) seasons because of light rain. It shows decreasing trends in the pre-monsoon (March-May) and monsoon (June-September) seasons because of heavy rainfall. The figure shows that when the value of the rainfall increases, the value of $PM_{2.5}$ decreases because pollutants directly deposit in the soil during the rainy season. Over the past decade, the trends in air quality over the past decade show $PM_{2.5}$ concentrations exceeding the national standards during the dry season, while remaining somewhat below the standards during the rainy season [20]. This might be due to rainfall, $PM_{2.5}$ concentration washes out in the wet season. But in dry season, $PM_{2.5}$ concentration shows a high peak in the absence of rainfall.

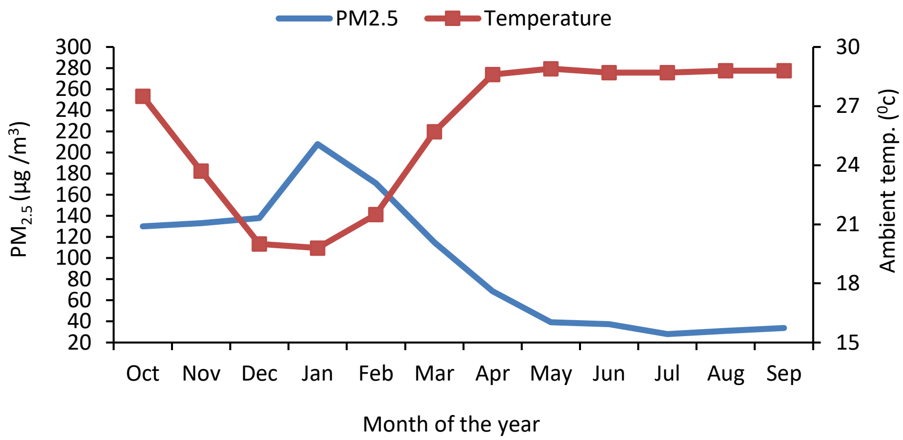

Fig.8. Relationship between $PM_{2.5}$ and rainfall.

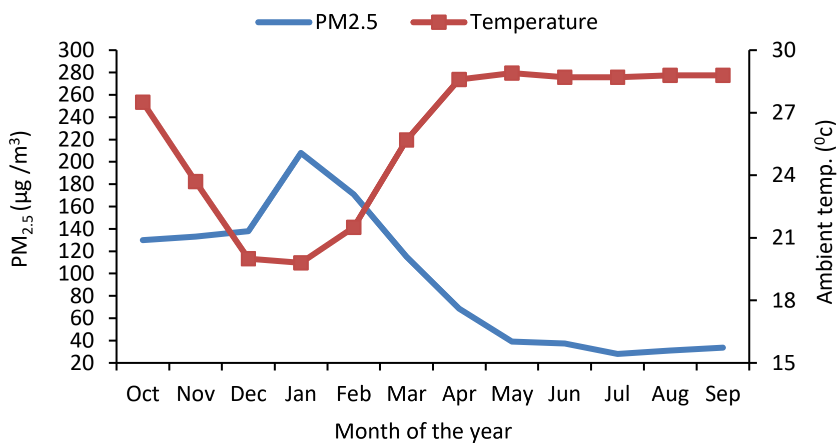

Fig.9. Relationship between $PM_{2.5}$ and ambient temperature.

3.3. Relationship between $PM_{2.5}$ and ambient temperature

Figure 9 shows that the ambient temperature effectively decreases the $PM_{2.5}$ mass concentrations through heat. Ambient temperature can effectively reduce atmospheric particulate matter. Besides, the relation between $PM_{2.5}$ and ambient temperature was negative, and $PM_{2.5}$ showed increasing trends from October 2017 to February 2018 in the post-monsoon and winter seasons. It shows decreasing trends from March 2018 to September 2018 in the pre-monsoon and monsoon seasons, respectively, when the ambient temperature shows a high peak. As shown in the Figure 9, when the value of the temperature increases, the value of $PM_{2.5}$ decreases. Another study found that in Kansas City, PM emissions exponentially increased as the temperature decreased due to ambient temperature. The $PM_{2.5}$ concentration dilutes in the wet season, but in the dry season, it shows a high peak when the ambient temperature shows the lowest value [30].

3.4. Relationship between PM_{10} and rainfall

As shown in Figure 10, precipitation can effectively decrease PM_{10} mass concentrations through a wet deposition. Precipitation can effectively remove atmospheric particulate matters, especially those that are smaller in size. The relation between PM_{10} and rainfall was negative, and PM_{10} showed increasing trends from November 2017 to January 2018 in the post-monsoon and winter seasons. Furthermore, the figure shows decreasing trends from February 2018 to August 2018 that cover the pre-monsoon and monsoon seasons. This fluctuation occurs because of heavy and light rainfall in different seasons. Figure 10 shows that when the value of the rainfall increases, the value of PM_{10} decreases; on the other hand, when the value of rainfall decreases, the value of PM_{10} increases. Since $PM_{2.5}$ and PM_{10} emit from the same source, the same phenomena occurs. Another study found that the increase of rainfall was negatively related to the average PM_{10} concentration in the Kathmandu valley [31]. Over the past decade, trends in air quality had large seasonal variations in PM_{10} concentrations due to wind direction, which suggested that brick-kilns were the major contributors of increased PM_{10} concentration in the Dhaka air during the dry season and PM_{10} reduction through wet deposition during wet season, considering the number of rainy days [20]. This might be due to rainfall since PM_{10} concentration washes out in the wet season. Still, the dry season PM_{10} concentration shows a high peak because many brick kilns go into operation in the winter. Monthly PM_{10} shows higher concentrations in the dry period than in the wet period.

3.5. Relationship between PM_{10} and ambient temperature

Figure 11 indicates that the relation between PM_{10} and ambient temperature is negative. PM_{10} increased from November 2017 to January 2018, including the seasons of late post-monsoon and early winter. The figure shows decreasing trends from February 2018 to August 2018 in the late winter and monsoon seasons, respectively, when the ambient temperature shows a high peak. However, when the temperature was increasing, the value of PM_{10} decreased. On the other hand, when the temperature was reduced, the value of PM_{10} increased (Figure 11). In a study, the PM emissions exponentially increased as the temperature decreased in Kansas City. This might be due to ambient temperature, where the PM_{10} concentration dilutes in the wet season, but shows a high peak in the dry season [30].

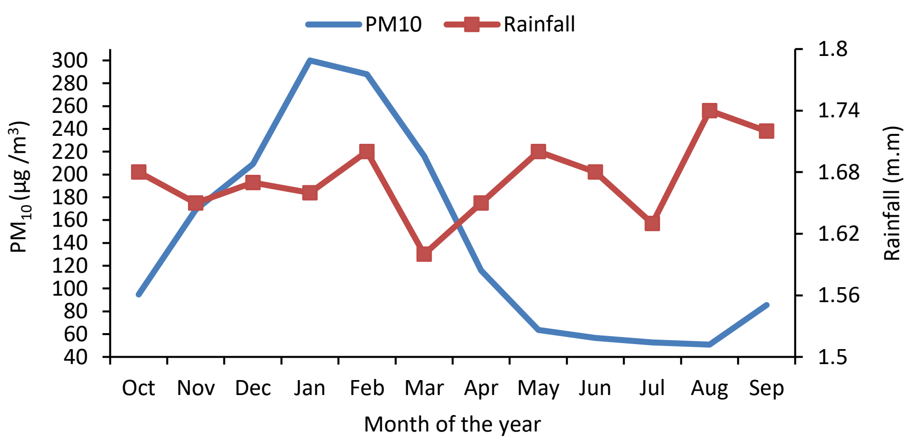

Fig.10. Relationship between PM_{10} and rainfall.

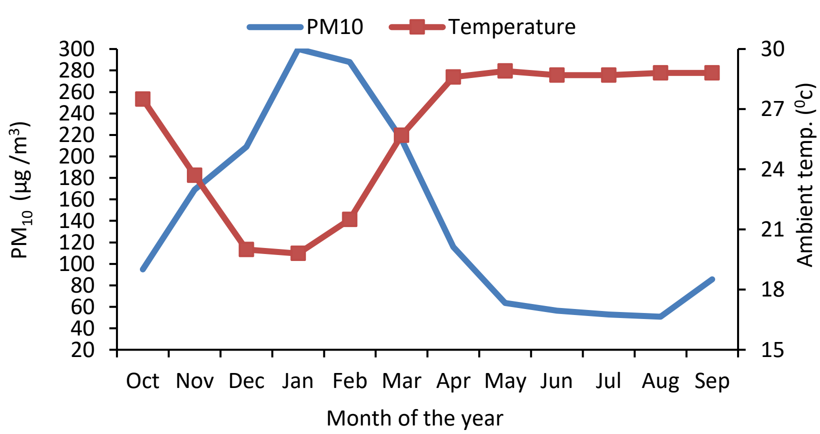

Fig.11. Relationship between PM_{10} and ambient temperature.

3.6. Correlation of some air properties with each other

Table 2 shows the linear relationship of some air properties with each other. The results indicate that $PM_{2.5}$ is positively and significantly correlated with PM_{10} (r=0.822**). SO_2 is negatively but significantly correlated with $PM_{2.5}$ (r=-0.745*) and PM_{10} (r=-0.735*).

3.7. Wind rose

There are four major monsoons in Bangladesh, namely pre-monsoon, monsoon, post-monsoon, and winter. The wind rose diagram of hourly wind direction and the wind speed for the four monsoons are illustrated in Figure 12. The wind is the strongest during the post-monsoon and originates mostly from the Northeast, whereas in the monsoon, the wind direction gradually changes to the southeast and lasts until the winter. The southwesterly wind during the pre-monsoon is generally milder but happens more frequently. This is due mainly to the different meteorological conditions portrayed by the different monsoons. The SEM is characterized by heavy rainfall and strong winds, while cloudless skies and drier weather accompany the NWW. Referring to Table 1, the average concentration of PM_{10} is 131 $\mu g/m^3$ for pre-monsoon, 132 $\mu g/m^3$ for post-monsoon, 61.4 $\mu g/m^3$ for the monsoon, and 266 $\mu g/m^3$ for winter. For $PM_{2.5}$, the average concentration is 74.2 $\mu g/m^3$ for pre-monsoon, 132 $\mu g/m^3$ for post-monsoon, 32.5 $\mu g/m^3$ for the monsoon, and 171 $\mu g/m^3$ for winter. As for NO_2, the average concentration was 16.3 ppb, 21 ppb, 8.1 ppb, and 42 ppb for pre-monsoon, post-monsoon, monsoon, and winter seasons, respectively. For SO_2, the highest average concentration was 8.4 ppm for the monsoon season, followed by 4.08 ppb, 1.90 ppb, and 5.3 ppb for post-monsoon, winter, and pre-monsoon, respectively. The concentration of PM_{10}, $PM_{2.5,}$ and NO_2 are higher during the winter, but not for SO_2. This could be due to stable drier meteorological conditions that cause hindrance to dispersion and removal of pollutants from the atmosphere. The highest average concentration of CO was recorded in the winter season (2.37 ppm), followed by the post-monsoon, pre-monsoon, and monsoon seasons with the values of 1.52 ppm, 1.66 ppm, and 0.73 ppm, respectively. The intervals for these three different monsoon categories did not overlap, indicating that all three had statistically significantly different concentrations of CO. The primary sources of CO are incomplete combustion of fossil fuels and biomass burning. Hydroxyl groups function as sinks to remove CO from the atmosphere. Due to the substantial deposition phenomena during the winter, hydroxyl groups are available in abundance, thus pairing up with the CO in the air and producing CO_2. The average concentration of O_3 is the highest in the post-monsoon, with the value of 6.83 ppb; next is 4.04 ppb in the winter, 2.92 ppb in the pre-monsoon and 2.92 ppb in the monsoon season. Most of the air in winter season comes to the sampling site from the northern part of the Gazipur district, where the brickfield zones are situated.

Table 2. Pearson correlation of air pollutant with each other.

Air pollutant	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**NO_2**	**CO**	**O_3**
$PM_{2.5}$	1					
PM_{10}	0.918**	1				
SO_2	-0.574	-0.518	1			
NO_2	0.897**	0.940**	-0.498	1		
CO	0.463	0.525	-0.259	0.604*	1	
O_3	0.526	0.245	-0.417	0.371	0.761*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

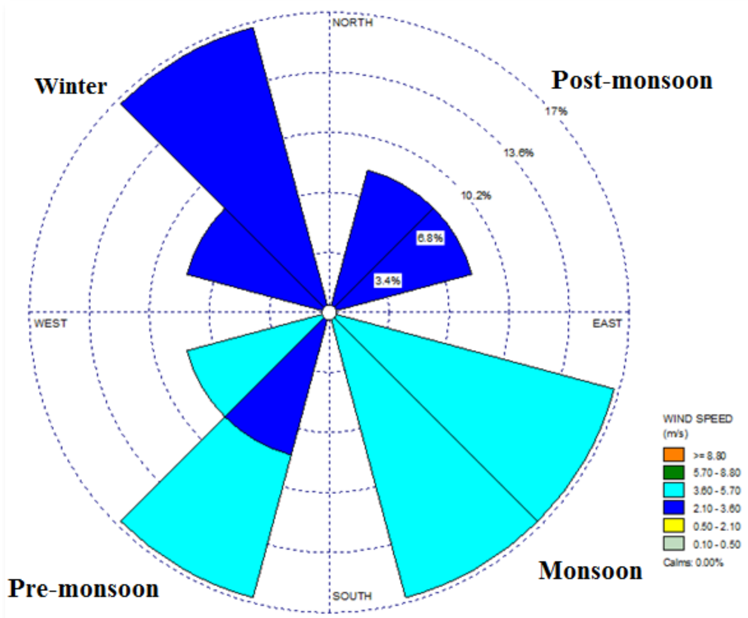

Fig.12. Wind rose diagram of pre-monsoon, monsoon, post-monsoon, and winter season.

3.8. Air Quality Index (AQI)

An AQI could be defined as a scheme that transforms the (weighted) values of individual air pollution-related parameters into a single number. First, the air quality rating of each parameter used for monitoring is calculated in each zone by the following formula:

q = 100xV/Vs

where, q = quality rating, V = observed value of the parameter, and Vs = value recommended for that parameter.

If the total number of 'n' of the parameters are considered for air monitoring, then the geometric mean of 'n' numbers of quality ratings are calculated in the following way:

g = anti log {(log a + log b +. log x)/n}

where, g = geometric mean; a, b, c, d, x = different values of the air quality rating; n = number of values of air quality rating; and log = logarithm.

3.8.1. Status of AQI variation in Gazipur

The monthly air quality index, which was calculated at Gazipur stations of CAMS-4, is shown in Table 3. The monthly AQI of the Gazipur station varies from 05 to 500 respectively during the study period from October 2017 to September 2018. The minimum and maximum AQI values in the post-monsoon season were 05 to 402, 28 to 500 in the winter season, 18 to 338 in the pre-monsoon season, and 9 to 181 in monsoon season.

Table 3. AQI Status in Gazipur (October 2017 to September 2018).

Seasons	The month of the year	Average AQI value	Minimum AQI value	Maximum AQI Value	Seasonal average
	October 2017	54.8	5	126	
Post-	November, 2017	174.53	44	402	114.66
	December, 2017	245.03	28	350	
Winter	January, 2018	369.06	306	500	309.13
	February, 2018	313.32	184	498	
	March, 2018	224.58	123	338	
Pre-	April, 2018	142.06	18	269	152.73
	May 2018	91.57	50	177	
	June 2018	81.05	20	178	
Monsoon	July, 2018	80.87	18	181	63.83
	August 2018	46.12	9	142	
	September, 2018	47.3	12	160	

3.8.2. AQI variation in different seasons

Table 4 shows the air quality index, range, and color level of different stages. Based on the data from CAMS-4, a monthly summary of the calculated AQI values showed that during the pre-monsoon season, the average AQI value (152.73) indicated the air quality was in the unhealthy category; in the monsoon season, the average AQI value (63.83) was in the moderate category. The post-monsoon season average AQI value (114.66) showed the air quality was in the caution category. The average AQI value (309.13) in the winter season indicated that the air quality was in the highly unhealthy category. A similar study was reported in Chittagong city, which means the environmental condition was totally unhealthy [33]. The pollutant is more acute in the winter season and lowers in the monsoon season because of the intensity of rainfall, temperature, and wind speed. In all cases, the most frequent responsible pollutant was $PM_{2.5}$ as well as PM_{10}.

Table 4. AQI (Air quality index) categories indicator.

Air quality index (AQI) Range	Category	Color
0-50	Good	Green
51-100	Moderate	Yellow Green
101-150	Caution	Yellow
151-200	Unhealthy	Orange
201-300	Very Unhealthy	Red
301-500	Extremely Unhealthy	Purple

(Sources: continuous air monitoring station, *CAMS-4, 2017-18)*

4. Conclusions

This study concentrated on major air pollutants (SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10}) determined by a continuous air monitoring station (CAMS-4) to find their seasonal variability. The highest peaks ($PM_{2.5}$=208 $\mu g/m^3$, PM_{10}=300 $\mu g/m^3$) were observed in January, and the lowest concentrations ($PM_{2.5}$=28 $\mu g/m^3$ and PM_{10}=52.8 $\mu g/m^3$) were detected during July and August in 2018. $PM_{2.5}$ and PM_{10} showed a positive correlation (r^2=0.842) with each other, indicating they came from the same source. Both $PM_{2.5}$ and PM_{10} were negatively correlated with temperature and rainfall. The average concentration of SO_2 showed the highest value (8.44 ppb) in the monsoon season (June-August) and the lowest value (1.90 ppb) in the winter season (December-February). In contrast, the concentration of O_3 (6.83 ppb) was measured in the post-monsoon (October-November), 2017. The highest NO_2 and CO (42.17ppb and 2.37ppm) concentrations were measured in the winter and the lowest concentration (8.17ppb and 0.73ppm) during the monsoon season. $PM_{2.5}$, PM_{10}, and NO_2 showed a positive correlation and a negative relationship with rainfall and ambient temperature. The AQI values of 52.73, 63.83, 114.66, and 309.13 indicated that the air quality during the pre-monsoon, monsoon, post-monsoon, and winter season was very unhealthy, cautious, unhealthy, and extremely unhealthy, respectively.

References

[1]. Mannucci, P. M., Franchini, M. (2017). Health effects of ambient air pollution in developing countries. *International journal of environmental research and public health*, *14*(9), 1048.

[2]. Maji, K. J., Dikshit, A. K., Deshpande, A. (2017). Assessment of City Level Human Health Impact and Corresponding Monetary Cost Burden due to Air Pollution in India Taking Agra as a Model City. *Aerosol and air quality research*, *17*, 831-842.

[3] Seyyednejad, S. M., Motamedi, H., Lordifard, P. (2017). Biochemical changes of Conocarpus erectus (combretaceae) respond to gas refinery air pollution as an air pollution indicator. *Pollution*, *3*(2), 185-190.

[4] Kanada, M., Dong, L., Fujita, T., Fujii, M., Inoue, T., Hirano, Y., Geng, Y. (2013). Regional disparity and cost-effective SO2 pollution control in China: A case study in 5 mega-cities. *Energy policy*, *61*, 1322-1331.

[5] World Health Organization. (2016). Ambient air pollution: A global assessment of exposure and burden of disease.

[6] Legge, A. H., Krupa, S. V. (1990). Acid Deposition: sulphur and nitrogen oxide. *Lewis, Chelsea, MI*.

[7] Houghton, R. A. (1999). The annual net flux of carbon to the atmosphere from changes in land use 1850–1990. *Tellus B*, *51*(2), 298-313.

[8] Protection E. (1996). Year-book (in Polish). Warszawa: GlownyUrzadStatystyczny. p. 169.

[9] Yu, I. T. S., Qiu, H., Wang, X., Tian, L., Tse, L. A. (2013). The synergy between particles and nitrogen dioxide on emergency hospital admissions for cardiac diseases in Hong Kong. *International journal of cardiology*, *168*(3), 2831-2836.

[10] Hasan, M. R., Hossain, M. A., Sarjana, U., Hasan, M. R. (2016). Status of air quality and survey of particulate matter pollution in Pabna city, Bangladesh. *American journal of engineering research*, *5*(11), 18-22.

[11] World Health Organization (2016). Household air pollution and health. Retrieved from www.who.int/mediacentre/factsheets/fs292/en/.

[12] World Health Organization (WHO) (2016). Household air pollution and health. Retrieved from www.who.int/mediacentre/factsheets/fs292/en

[13] Environmental Protection Agency (EPA) (2016). Particulate Matter (PM). Retrieved from www3.epa.gov/pm/basic.html

[14] Heal, M. R., Heaviside, C., Doherty, R. M., Vieno, M., Stevenson, D. S., Vardoulakis, S. (2013). Health burdens of surface ozone in the UK for a range of future scenarios. *Environment international*, *61*, 36-44.

[15] Hu, J., Wang, Y., Ying, Q., Zhang, H. (2014). Spatial and temporal variability of $PM_{2.5}$ and PM_{10} over the North China Plain and the Yangtze River Delta, China. *Atmospheric environment*,*95*, 598-609.

[16] Chen, R., Huang, W., Wong, C. M., Wang, Z., Thach, T. Q., Chen, B., CAPES Collaborative Group. (2012). Short-term exposure to sulfur dioxide and daily mortality in 17 Chinese cities: the China air pollution and health effects study (CAPES). *Environmental research*, *118*, 101-106.

[17] Bangladesh Bureau of Statistics (BBS) (2015). Population census 2015: Community report, narayanganj: Bangladesh bureau of statistics, Statistics division, Ministry of planning, Government of the people's republic of Bangladesh (GoB).

[18] Clean Air and Sustainable Environment (CASE) (2016). Air quality status and trends: 2013 2015. Department of environment: Clean air and sustainable environment project. Government of the people's republic of Bangladesh, Ministry of environment and forest.

[19] Ahmmed, K. M. T., Begum, D. A. (2010, September). Air pollution aspects of Dhaka city. In *proceedings of international conference on environmental aspects of Bangladesh (ICEAB10)*.

[20] Islam, M. M., Afrin, S., Ahmed, T., Ali, M. A. (2015). Meteorological and seasonal influences in ambient air quality parameters of Dhaka city. *Journal of civil engineering*, *43*(1), 67-77.

[21] Srinivas, J., Purushotham, A. V. (2013). Determination of air quality index status in industrial areas of Visakhapatnam, India. *Research journal of engineering sciences*, *2*(6), 13-24.

[22] Hoque, M. M., Begum, B. A., Shawan, A. M., Ahmed, S. J. (2015). Particulate matter concentrations in the air of Dhaka and Gazipur city during winter: A comparative study. *ICPSDT-2015) (August 19-20, 2015), Department of physics, CUET*.

[23] Sikder, H.A., M. Nasiruddin, J. Suthawaree, S. Kato, Kajii, Y. (2010). Observation of atmospheric pollutants in Dhaka, Bangladesh, PA03. Proc. of international conference on environmental aspects of Bangladesh.

[24] Huang, R. J., Zhang, Y., Bozzetti, C., Ho, K. F., Cao, J. J., Han, Y., Prévôt, A. S. (2014). High secondary aerosol contribution to particulate pollution during haze events in China. *Nature*, *514*(7521), 218-222.

[25] Chakraborty, A., Gupta, T., Tripathi, S. N. (2016). Chemical composition and characteristics of ambient aerosols and rainwater residues during Indian summer monsoon: Insight from aerosol mass spectrometry. *Atmospheric environment*, *136*, 144-155.

[26] Azad, A. K., Kitada, T. (1998). Characteristics of the air pollution in the city of Dhaka, Bangladesh, in winter. *Atmospheric environment*, *32*(11), 1991-2005.

[27] Kgabi, N. A., Sehloho, R. M. (2012). Seasonal variations of tropospheric ozone concentrations. *Global journal of science frontier research chemistry*, *12*, 21-29.

[28] ABDUL-WAHAB, S. A., Bouhamra, W. S. (2004). Diurnal variations of air pollution from motor vehicles in a residential area. *International journal of environmental studies*, *61*(1), 73-98.

[29] Sahu, L. K., Lal, S. (2006). Distributions of C2–C5 NMHCs and related trace gases at a tropical urban site in India. *Atmospheric environment*, *40*(5), 880-891.

[30] Nam, E., Kishan, S., Baldauf, R. W., Fulper, C. R., Sabisch, M., Warila, J. (2010). Temperature effects on particulate matter emissions from light-duty, gasoline-powered motor vehicles. *Environmental science and technology*, *44*(12), 4672-4677.

[31] Giri, D., Adhikary, P., Murthy, V. (2008). The influence of meteorological conditions on PM10 concentrations in Kathmandu Valley. *International journal of environmental research, 2*(1), 49-60.

[32] Guo, L. C., Bao, L. J., She, J. W., Zeng, E. Y. (2014). Significance of wet deposition to removal of atmospheric particulate matter and polycyclic aromatic hydrocarbons: A case study in Guangzhou, China. *Atmospheric environment, 83*, 136-144.

[33] Hossen, M. A., Hoque, A. (2016). Variation of ambient air quality scenario in Chittagong City: A case study of air pollution, 8, 1-9.