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Research Paper

Assessment of Seasonal Variations of Air Quality and AQI Status: Evidence from Chittagong, Bangladesh

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Abstract

With the rate of fast urbanization, the devasting effects of air pollution are spreading across the globe. Due to its connection to people's health, air quality should be given more importance than other environmental measures. Air pollution is considered a cause of many human diseases. Therefore, this study intends to investigate seasonal variation of air quality and "Air Quality Index (AQI)" in Chittagong city due to its volume, large population density, and importance as a commercial capital city of Bangladesh. Air pollution data on PM_{10}, $PM_{2.5}$, NO_2, NOx, SOx, CO, and O_3 levels have been collected from TV station, Khulshi Continuous Air Monitoring Station (CAMS). Component-specific analyzers have been used to continuously measure trace gases where O_3 is observed with a UV photometric analyzer. This study detect the highest peak ($PM_{2.5}$= 93.5 $\mu g/m^3$, PM_{10}= 210 $\mu g/m^3$) in January and the lowest concentrations ($PM_{2.5}$= 14.6 $\mu g/m^3$ and PM_{10}= 26.9 $\mu g/m^3$) during July and August. The highest average concentration has been recorded as the value of SO_2= 12.8 ppb (monsoon season), NO_2= 64.9 ppb (pre-monsoon), CO= 1.2 ppm (monsoon) and lowest SO_2= 3.2 ppb (winter season), NO_2= 24.4 ppb (monsoon), CO= 0.6 ppm (pre-monsoon) respectively. The AQI values (223.6), (109.5), (194.5), and (317.3) indicate that the air quality during the pre-monsoon, monsoon, post-monsoon, and winter season is very unhealthy, cautious, unhealthy, and extremely unhealthy, respectively.

Keywords
Air Quality Index, SO_2, NO_2, CO, O_3, Wind Rose

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1. INTRODUCTION

The port city of Chittagong is located in southern Bangladesh. The "Bay of Bengal" borders the city on the southwest and the eastern side is bordered by hills. The city is traversed by the Karnaphuli River, one of Bangladesh's most stunning rivers, which empties into the Bay of Bengal (Hossen and Hoque, 2016). Summers are warm and moist, and winters are cool and dry throughout the city, which has a 'tropical' wet and dry climate. Monsoon temperatures range from 29 to 35 degrees Celsius, while winter temperatures range from 12 to 17 degrees Celsius (Hossen and Hoque, 2016). The city receives an average of 2159 mm (85 inches) of rainfall each year, with high of 3810 mm (150 inches). During the monsoon season, which lasts from May to September, over 80% of the rain falls. The summer winds are often out of the southeast. During the winter, easterly and northeasterly winds prevail.

It has one of the highest densities of population in the nation and has a lot of air pollution. (Begum et al., 2004; Azad and Kitada, 1998; Hoque et al., 2020). Chittagong, the majority of the nation's urban communities that are polluted as a result of urbanization, poorly maintained cars, biomass/coal consumption for cooking and in block furnaces, building supplies, and road dust. As stated by World Bank, air pollution causes approximately 10,800 rash deaths and numerous million episodes of disease each year. The annual economic cost of illness and mortality in Dhaka is estimated to be between $132 and $583 million (Brandon, 1997). A similar situation has been examined for Dhaka, Bangladesh's second largest city, which has banned the two-stroke motor vehicle due to emission of air particulate matter (Begum et al., 2006).

One of the biggest issues in the world's least developed nations is air pollution in large cities. Along with this, human exposure to air pollution is increasing in many metropolitan areas, supermarket run malls, and entertaining which caused by vehicular induced turbulence (Begum et al., 2009). Sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) are two of the most common major toxins in the atmosphere because of their detrimental effects on plants and human health. Nitrogen oxides (NO_2) have a role in the production of photochemical oxidants in these materials and the acidification of the environment (Legge and Krupa, 1990). NO_2 donates to the formation of stratospheric ozone (O_3) and the lifespan of gase emission, both of which are thought to be important contributors to global warming (Houghton, 1990).

In Chittagong City, vehicle travel is thought to be the only most significant source of air contamination. The opacity of smoke produced by various diesel vehicle emissions is now the dominant cause of air contamination (Rouf et al., 2008; Salam et al., 2003). Significant amounts of black diesel smoke are produced as a result of the heavy traffic, the choking nature of the traffic, the age and heavy weight of the majority of trucks, and the heavy traffic (Begum et al., 2004; Chueinta et al., 2000; Hopke et al., 2011). For the months of December 2006 and December 2007, Begum et al. (2012) looked into the ground-level ozone levels in the surrounding air of Chittagong City. A new study used satellite TV and ground clarifications to show that the dust season lasts April to August, with human assistances peaking in late summertime (Farahat et al., 2015). Dust erosion occurs throughout the year, with low levels in the winter and high levels in June and July (Shao, 2008).

Both emerging and developed countries have increased public awareness of air quality as a result of problems related to air pollution (Kurt and Oktay, 2010). Numerous air contaminants, for instance carbon monoxide (CO), RSPM, SO_2, NO_2, SPM, ozone (O_3), and others, have negative health effects in polluted air. The high concentrations of these contaminants are potentially fatal affecting alive difficulty, nuisance, and lightheadedness as well as heart disease (Künzli et al., 2000). As a result, the experts recommend that criterion pollutants in the air be monitored and forecasted. In the majority of examinations into air contamination, Gaussian dispersion models are used to anticipate air quality primarily on a physical basis, providing exact details about the path of contaminants (Chelani et al., 2002). It is estimated that air pollution contributes to close to 3,580 deaths, 10 million days of restricted activity, and 87 million days of respiratory discomfort annually (Asia, 2006). The high influx of population to urban areas, approximately 3 million people die each year, 9% of lung cancer deaths, 17% of pulmonary disease deaths, more than 30% of heart disease deaths, and 9% of respiratory infection deaths due to increase in consumption patterns and unplanned urban and industrial development in the world (Hoque et al., 2022; Mukta et al., 2020; Hoque et al., 2020; Uddin et al., 2014; Ahmed and Hossain, 2008). Based on Air Pollution Management Project (AQMP), Dhaka is liable for a projected 15,000 early deaths and quite a few million cases of pulmonary, respiratory, and neurological disorders. WHO reported that, vehicle is a foremost source of breathing suffering in metropolitan Bangladesh.

The AQI (air quality index) is a numerical indicator that determines how terrible or excellent the air quality is for inhabitants based on measured amounts of chosen ambient air pollutants. To preserve human health and environmental resources, AQI used to explain the degree of urban air contamination. It's also used to evaluate pollution-reduction efforts and track changes in surrounding air excellence (Plaia, 2011). The AQI is a daily collection of ambient air pollutants monitoring that is reported using an index or rating scale (Van den Elshout et al., 2008). Cogliani (2001) utilized a regression model to anticipate air contamination in cities using an air pollution index that was closely associated with meteorological data. Therefore, the study was determined the concentration of various pollutants like SO_2, NO_2, O_3, CO, and SPM to find the seasonal variations of air pollutants in Chittagong city and to determine the "Air Quality Index (AQI)" value.

2. EXPERIMENTAL SECTION

In Chittagong, a "Continuous Air Monitoring Station (CAM S)" was used to quantity certain contaminants. In Khulshi there is a "Chittagong Television Station Camps", which are on a hilltop about 2.5 km northwest of the downtown and about 100 meters beyond the immediate zone, are where the CAMS is located. This place is comparatively undisturbed by neighboring air pollution sources due to the terrain of the city (hilly area) and the lack of a substantial source of air pollution close by. It represents the levels of air pollution at that altitude in a 500 meter circle around the place. This will be a section of the monitoring station where contamination from the surrounding region will be avoided.

2.1 Features of Study Area

The study was conducted at TV station, Khulshi in Chittagong city (Figure 1) in which was approximately at the latitude 22.32^{o}N and longitude 91.81^{o}E. Chittagong is located in the southern portion of the Country. The amazing city is choked with aged, greatly contaminating vehicle fleet (Chakma et al., 2021). Additionally, the city is home to a large number of minor factories. Moreover, the city is constantly being expanded with new roads and structures. High influx of residents from rural areas, badly maintained automobiles, and cooking with biomass or coal. This made a significant dust in the city's air (CASE, 2016). Due to the enormous amount of moving vehicles in Chittagong city, this area was also described as being congested. This area, which was semi-residential, was also affected by the wintertime emissions from brick kilns on the northern side of Chittagong. About 100 meters separated the CAMS location from the main road. The height of the roof was 1.8 m above the roof, and the sampler's intake nozzle was approximately 7 meters

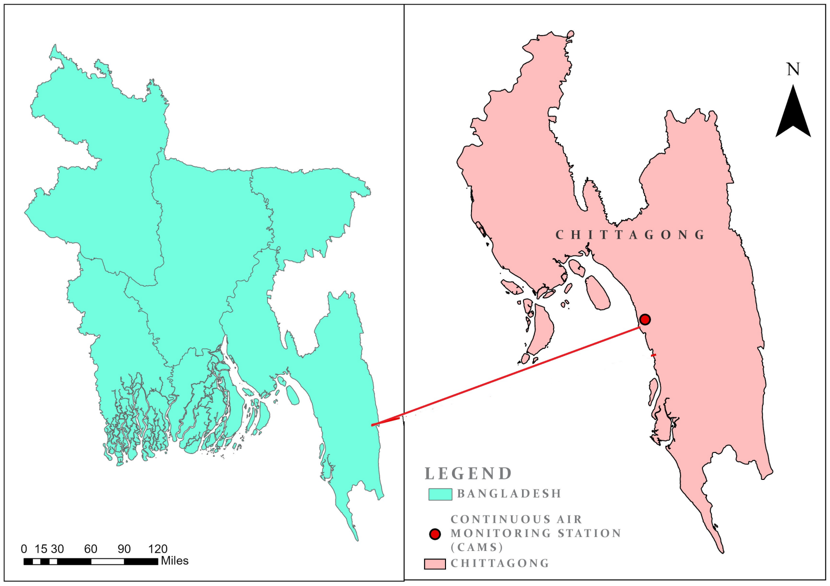

Figure 1. Map Showing the Study Area of Chittagong (CAMS-6, TV Station-Khulshi)

above the ground (CASE, 2016). The Khulshi TV station was a hotspot location because it was close to numerous important crossroads of roads and had a lot of traffic flowing through it.

2.2 Materials

From August 2017 to July 2017, measurements of trace gases were made at the Continuous Air Monitoring Station (CAMS), close to a TV station in the Khulshi neighborhood of Chittagong (latitude 22.32^{o}N; longitude 91.81^{o}E). Because of the enormous amount of automobiles, this location is often known as traffic move around the TV station, Khulshi in Chittagong city. Air pollution data on PM_{10}, $PM_{2.5}$, NO_2, NOx, SOx, CO, and O_3 levels were collected from TV station Khulshi. Significant levels of air pollution in Chittagong City were found using the Statistical Analysis Software (SAS).

2.3 Methods

At CAMS, four gas analyzers were displayed: one for sulfur dioxide (SO_2), one for carbon monoxide (CO), one for nitrogen oxides (NOx), and one for ozone (O_3). They were continuously measuring the current levels of SO_2, CO, NOx, and O_3 in the atmosphere. These analyzers were used for continuous measurement of trace gases where O_3 was observed with a UV photometric analyzer (Teledyne Monitor Labs (TML), Inc., model 9810B); CO using a non-dispersive infrared spectrometer (TML, model 9830B). NO, NO_2 and NOx using chemiluminescence analyzer (TML, model 9841B) and SO_2 were measured using a pulsed UV fluorescence analyzer (TML, model 9850B), respectively. All instruments were contained in a cooled room and calibration were accomplished times to time. All calibration procedures were noticeable based on the "National Institute of Standards and Technology (NIST)" regulation.

3. RESULTS AND DISCUSSION

3.1 Seasonal Variation of Air Quality in Chittagong City

Table 1 displays the periodic variance of 6 (six) air pollutants from the study area are SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10}. Pre-monsoon and post-monsoon seasons were followed by winter and the monsoon, with the exception of NO_2 and O_3.

3.1.1 Seasonal Variation of $PM_{2.5}$

Figure 2 displays the seasonal fluctuations in "$PM_{2.5}$" concentrations in the city of Chittagong from post-monsoon (October and November) through winter (December to February), pre-monsoon (March to May), and monsoon (June to September). During the observations, the highest value of $PM_{2.5}$ was 93.5 μg/m^3 during January 2018, and lowest was 14.6 μg/m^3 in July 2018. Furthermore, in Bangladesh standard annual value of $PM_{2.5}$ is 15 μg/m^3 whereas, the average value (53.80 μg/m^3) of $PM_{2.5}$ in the present study is 4th times greater than the annual regulatory national standard (Ahmmed and Begum, 2010). The highest concentration of $PM_{2.5}$ during the winter months was linked to increased air emissions from burning biomass and fossil fuels as well as poor weather conditions for pollution dispersion (Hoque et al., 2020).

3.1.2 Seasonal Variation of PM_{10}

In Figure 3, the highest value of PM_{10} (210 μg/m^3) found in January and lowest value (26.9 μg/m^3) found in July. Bangladesh's standard annual value of PM_{10} is 50 μg/m^3

Table 1. Seasonal Variation of SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10} in Chittagong City

Season	Pollutants Concentration					
	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	SO_2 (ppb)	NO_2 (ppb)	O_3 (ppb)	CO (ppm)
Post-monsoon	52.3	102.2	3.7	29.5	5.3	0.62
Winter	77.5	186.7	3.2	34.3	4	0.93
Pre-monsoon	62.9	114.6	9.9	63.9	3.6	0.6
Monsoon	21.7	57.3	12.8	24.4	5.2	1.2
BNAAQS	65	150	140	100	80	10

Note: Bangladesh National Ambient Air Quality Standard

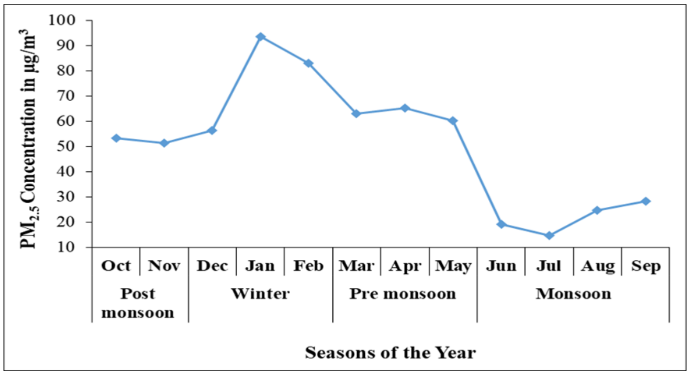

Figure 2. Seasonal Variation of $PM_{2.5}$ Concentration in Chittagong City

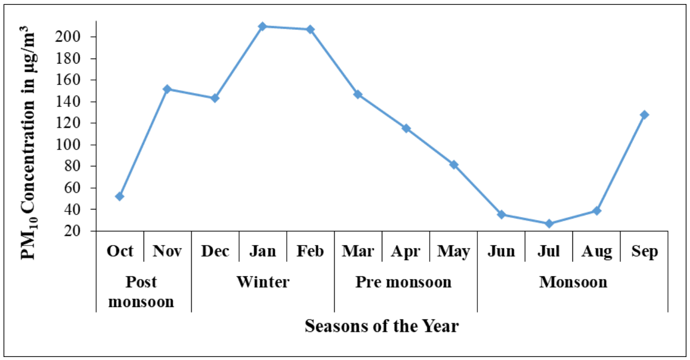

Figure 3. Seasonal Variation of PM_{10} Level in Chittagong City

that is two and half times lesser than the average annual value (111.43 $\mu g/m^3$) of the current study (Ahmmed and Begum, 2010). A related study was accompanied in Chittagong (Rouf et al., 2012) and in Andhra Pradesh (Srinivas and Purushotham, 2013), where the highest and lowest concentration were found in January and July. This pollutant level was exceeding the average standard. It may be happened because of little rainfall in the winter season, and the number of "CNG" automobiles progressively increasing in the city area since 2007 might be responsible for the improving the condition (Rouf et al., 2012).

3.1.3 Seasonal Variation SO_2

Figure 4, depicted that the SO_2 level warding trends from February to April and May to July. The highest level of SO_2 (12.81 ppb) found in monsoon season 2018 and the lowest level of SO_2 (3.24 ppb) in the winter season 2017. Similar studies were observed in Chittagong city (Hossen and Hoque, 2016) and in Chittagong (Rouf et al., 2012). The highest peak was found in a wet season where coal-fired power plants and industry considering the primary source of pollutants contributing to these air quality problems. The concentration of SO_2 is nine (9) times lower than the Bangladeshi standard (Ahmmed and Begum, 2010).

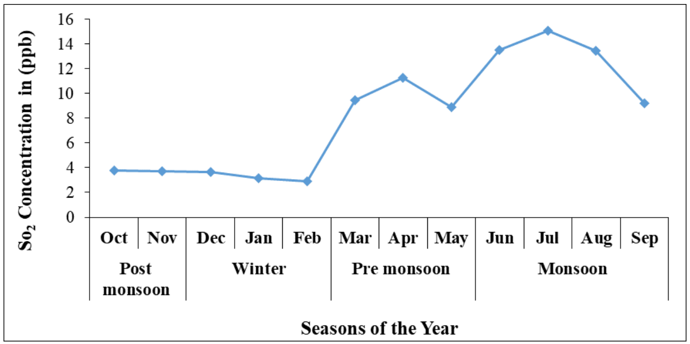

Figure 4. Seasonal Variation of SO_2 Concentration in Chittagong City

3.1.4 Seasonal Variation of NO_2

During the observations, the highest concentration of NO_2 (63.90 ppb) was discovered in the pre-monsoon season, and the lowest concentration of NO_2 (24.38 ppb) was measured in the monsoon season (Figure 5). Similar studies were reported in Chittagong city (Hossen and Hoque, 2016) and other areas in Chittagong (Rouf et al., 2012). Even though, monsoon period because of rain, moderate wind speed, and the maximum temperature is responsible for decreased pollution concentration (Rouf et al., 2012). NO_2 emission are produced primarily from vehicle, power plant and other equipment. Ahmmed and Begum (2010) show the Bangladesh standard value of NO_2 is one and half times lower than the current study.

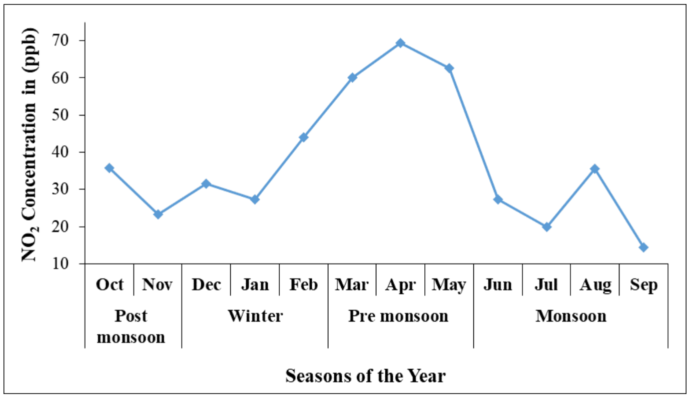

Figure 5. Seasonal Variation of NO_2 Level in Chittagong City

3.1.5 Seasonal Variation of O_3

Figure 6 depicted that the uppermost concentration of O_3 (5.34 ppb) was seen in the post-monsoon season, and the minimum level of O_3 (3.58 ppb) was measured in the pre-monsoon. After the highest peak of O_3 concentration the study area demonstrations the decreasing trends in March to August. Ahmmed and Begum (2010) show the Bangladesh standard value of O_3 is eighteen times lower than present study.

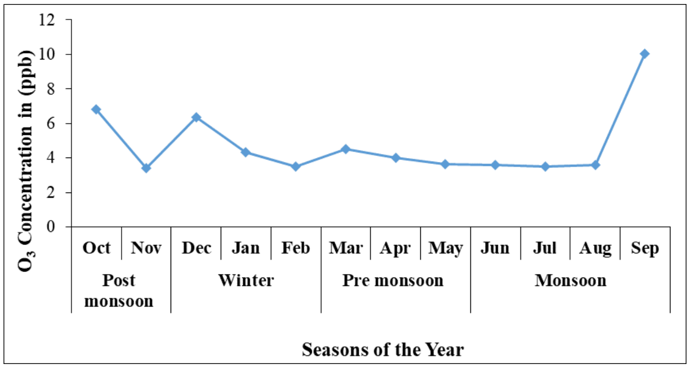

Figure 6. Seasonal Variation of O_3 Concentration in Chittagong City

3.1.6 Seasonal Variation of CO

Figure 7 displayed that the maximum level of CO (1.26 ppm) found in the wintertime, and the minimum level of CO (0.60 ppm) was measured in pre-monsoon season. Similar study was reported in the winter period in Chittagong City, which may be attributed from industrial sources, vehicles circulating as well as some 'meteorological factors' such as weaker wind speed, irregular rainfall (Rouf et al., 2012). The current concentration of CO is ten times lower than the average annual standard value (Ahmmed and Begum, 2010).

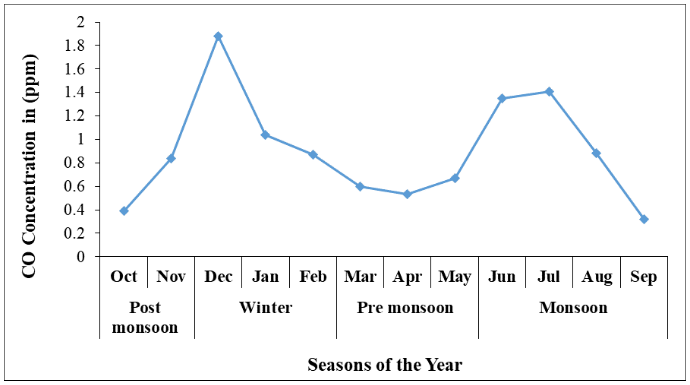

Figure 7. Seasonal Variation of CO Concentration in Chittagong City

3.2 Relationship between $PM_{2.5}$ and Rainfall

Precipitation has a significant impact on $PM_{2.5}$ concentrations during the monsoon season (June, July, August, and September), as seen in Figure 8(a). With plenty of precipitation during these four months, $PM_{2.5}$ concentrations drastically dropped during the monsoon season. According to some reports, precipitation can lower the amount of dust present and mostly removes coarse particles while having little impact on tiny particles. These anomalous precipitation events have a tendency to remove too much $PM_{2.5}$ from the atmosphere. On the other hand, the concentration of $PM_{2.5}$ grew quickly with little precipitation throughout the winter months of December, January, and February. This graph shows how rain and $PM_{2.5}$ have an opposite relationship. According to changes in air quality over the past ten years detailed by Islam et al. (2015), $PM_{2.5}$ concentrations were higher than the national limits during the post-monsoon and winter seasons but were slightly lower during the monsoon season.

3.3 Relationship between $PM_{2.5}$ and Ambient Temperature

The relationship between air temperature and $PM_{2.5}$ concentrations is shown to be negative in Figure 8(b). Due to intense radiation heating the city's subsurface, $PM_{2.5}$ concentrations drastically dropped as air temperatures soared. Since the lower atmosphere is less stable and becomes more turbulent, contaminants can spread more easily. As a result, during the pre-monsoon and monsoon seasons, the likelihood of atmospheric pollution decreased. On the other hand, in the winter season (December, January and February), air temperature remains low, and the concentration of $PM_{2.5}$ was significantly increased.

3.4 Relationship between PM_{10} and Ambient Temperature

In Figure 8(c) PM_{10} shows similar trends that of $PM_{2.5}$. Ambient temperature effectively decreases PM_{10} mass concentrations through heat. PM_{10} shows increasing trends from November 2017 to February 2018 and decreasing trends from March, 2018 when ambient temperature shows the high peak in March, 2018. The relation between PM_{10} and ambient temperature was negative. This might be due to ambient temperature, PM_{10} concentration dilutes in monsoon season, but in the winter season, PM_{10} attention shows a high peak.

3.5 Relationship between PM_{10} and Rainfall

In Figure 8(d) PM_{10} shows similar trends that of $PM_{2.5}$. In the monsoon season (June, July, August, and September), precipitation has a significant impact on concentrations of PM_{10}.In the monsoon season, concentrations of PM_{10} decreased significantly by reducing dust and coarse particles during excessive precipitation. Reversely, in the winter time (December, January, and February) concentration of PM_{10} increased rapidly with a small precipitation. This figure indicates the negative relationship between PM_{10} and rainfall. ?ound in their studies that an increase of rainfall has negative relation with average PM_{10} concentration in Kathmandu valley might be due to rainfall in the monsoon season. All occurrences, both of natural and artificial origin, that have an impact on the amount of particulate matter suspended in the near-ground troposphere are directly related to the rate of change in the PM_{10} concentration as a local characteristic.

3.6 Relationship among Air Properties

Table 2 shows the linear relationship among 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 PM10 (r= -0.735*).

3.6.1 Correlation between $PM_{2.5}$ and PM_{10}

A scatter plot was used to provide a better overview and interpretation of the correlations between $PM_{2.5}$ and PM_{10}. Slope and R^2 values were calculated from simple linear regression plots of $PM_{2.5}$ and PM_{10} where $PM_{2.5}$ as the X axis and PM_{10} as Y axis. The study founded that there was a significant positive relationship between $PM_{2.5}$ and PM_{10} because both of PM_{10} and $PM_{2.5}$ comes from the same source. Figure 9(a) represented that the value of PM_{10} is increasing with the increasing of $PM_{2.5}$ and there was a strong positive relationship between them (r= 0.822). The regression line has a relation that is y= 2.125x + 3.017.

3.6.2 Correlation between SO_2 and $PM_{2.5}$

A scatter plot was used to provide a better overview and interpretation of the correlations between SO_2 and $PM_{2.5}$. Slope and R^2 values were calculated from simple linear regression plots of SO_2 and $PM_{2.5}$ where SO_2 as X axis and $PM_{2.5}$ were Y axis. The study founded that there was a significant negative relationship between SO_2 and $PM_{2.5}$. The graph in the Figure 9(b) represented that the value of $PM_{2.5}$ is increasing with the decreasing of SO_2, and there was a negative relationship between them (r= -0.745). The regression line have a relation that is y= -4.060x + 84.21.

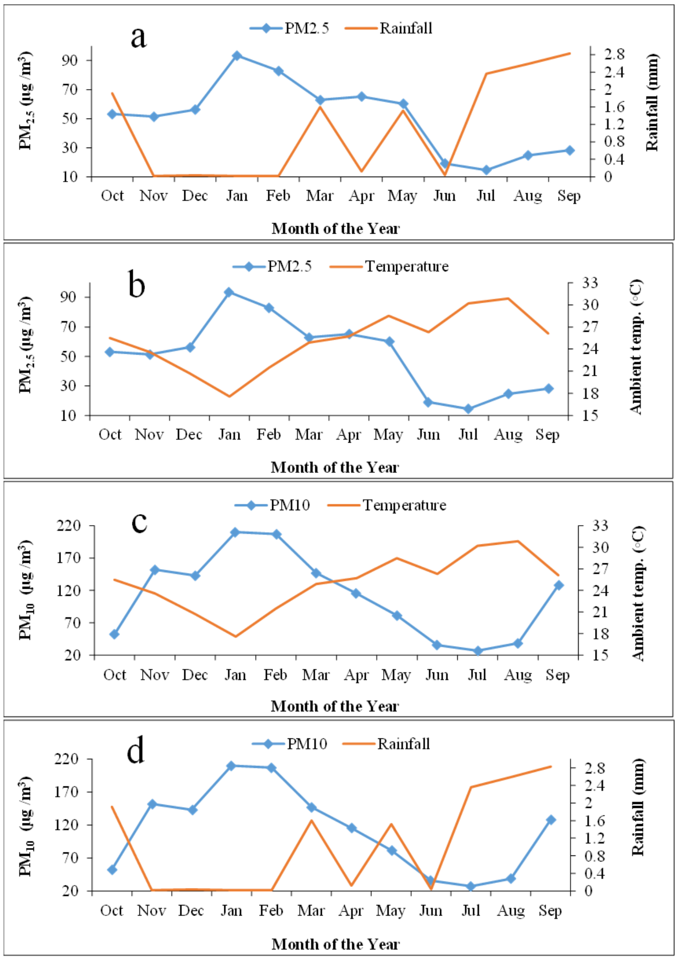

Figure 8. Relationship between (a) $PM_{2.5}$ and rainfall (b) $PM_{2.5}$ and ambient temperature, (c) $PM_{2.5}$ and ambient temperature and (d) $PM_{2.5}$ and rainfall

3.6.3 Correlation between SO_2 and PM_{10}

A scatter plot was used to provide a better overview and interpretation of the correlations between SO_2 and PM_{10}. Slope and R^2 values were calculated from simple linear regression plots of SO_2 and PM_{10}, where SO_2 as X axis and PM_{10} as Y axis. The study founded that there was a significant negative relationship between SO_2 and PM_{10}. Figure 9(c) represented that the value of PM_{10} is increasing with the decreasing of SO_2, and there was a negative relationship between them (r= -0.735), and the regression line have a relation that is y= -10.35x + 196.

Table 2. Pearson Correlation Coefficient of Air Pollutants in Chittagong City

Air Pollutants	SO_2	NO_2	O_3	CO	$PM_{2.5}$	PM_{10}
SO_2	1					
NO_2	0.058	1				
O_3	-0.169	-0.446	1			
CO	0.47	-0.289	-0.545	1		
$PM_{2.5}$	-0.745**	0.456	-0.153	-0.418	1	
PM_{10}	-0.735**	0.092	0.095	-0.385	0.822**	1

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

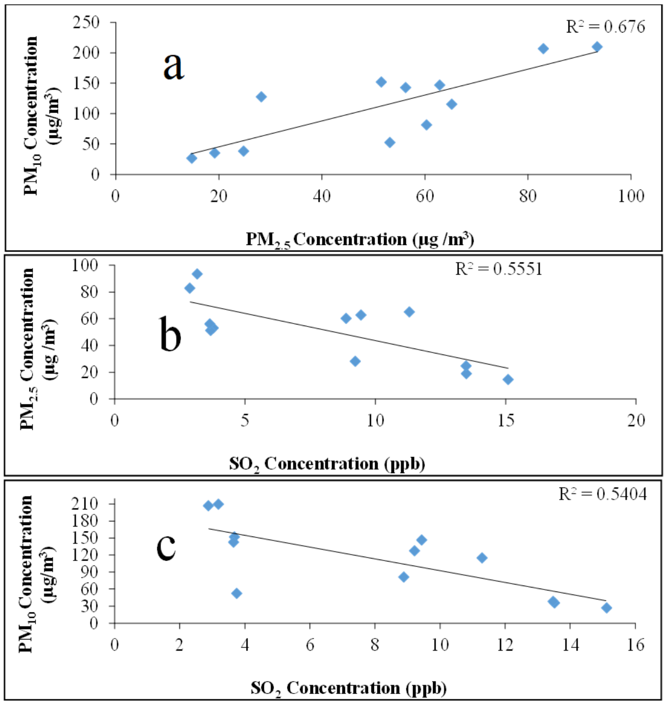

Figure 9. Correlation between (a) $PM_{2.5}$ and PM_{10} (b) SO_2 and $PM_{2.5}$ and (c) PM_{10} and SO_2

In addition to these direct (i.e. primary) emissions of particles, the chemical interactions of gases like sulphur dioxide can also result in the formation of $PM_{2.5}$ (SO_2). We refer to these as secondary particles. It is frequently advantageous to take action to lower the emissions of these precursor gases in order to lower $PM_{2.5}$ concentrations in general.

3.7 Wind Rose

In Bangladesh, there are four main monsoon seasons: pre-monsoon (which blows from March to May), monsoon (which blows from June to September), post-monsoon (which blows from October to November), and winter (December to February). Figure 10 displays the hourly wind direction and speed for the four monsoons. The wind is highest during the monsoon and often comes from the southeast, as opposed to the monsoon, when the wind direction gradually moves to the southeast and lasts until the winter. Pre-monsoon winds from the southwest are often gentler but more frequent. This is mostly caused by the distinct weather conditions that each monsoon represents. While the NWW are accompanied by clear skies and drier weather, the SEM are marked by heavy rainfall and high winds.

Mentioning to Table 1, the average concentration of PM_{10} is 114.59 $\mu g/m^3$ for "pre-monsoon", 102.2 $\mu g/m^3$ for "post-monsoon", 57.27 $\mu g/m^3$ for the "monsoon", and 186.67 $\mu g/m^3$ for "winter". For $PM_{2.5}$, the average concentration is 62.90 $\mu g/m^3$ for "pre-monsoon", 52.3 $\mu g/m^3$ for "post-monsoon", 21.68 $\mu g/m^3$ for the "monsoon", and 77.53 $\mu g/m^3$ for "winter", As for the NO_2, the reported average concentration was 63.91 ppb, 29.45 ppb, 24.38 ppb and 34.33 ppb for "Pre-monsoon", "Post monsoon", "Monsoon", and "winter" respectively whereas for SO_2, the highest average concentration was 12.82 ppb for monsoon season, followed by 9.88 ppb, 3.73 ppb, and 3.25 ppb for pre-monsoon season, post-monsoon season and winter season accordingly. Except for SO_2, the winter season sees greater levels of PM_{10}, $PM_{2.5}$, and NO_2. This could be as a result of the regular, drier weather patterns that prevent toxins from dispersing and being removed from the atmosphere.

Monsoon season had the greatest average CO concentration (1.24 ppm), followed by pre-monsoon season (0.60 ppm), post-monsoon season (0.62 ppm), and winter (0.93 ppm), in that order. The fact that the ranges for the three separate monsoon groups do not overlap shows that the CO concentrations in each of the three monsoons are statistically different. Burning biomass and incomplete combustion of fossil fuels are the main sources of carbon monoxide.

3.8 Air Quality Index (AQI)

A method for converting the (weighted) values of various air pollution-related metrics into a single number is known as an "AQI". The initial calculation of each monitoring parameter's air quality rating in each zone uses the following formula:

$$q = 100 \times V/Vs \quad (1)$$

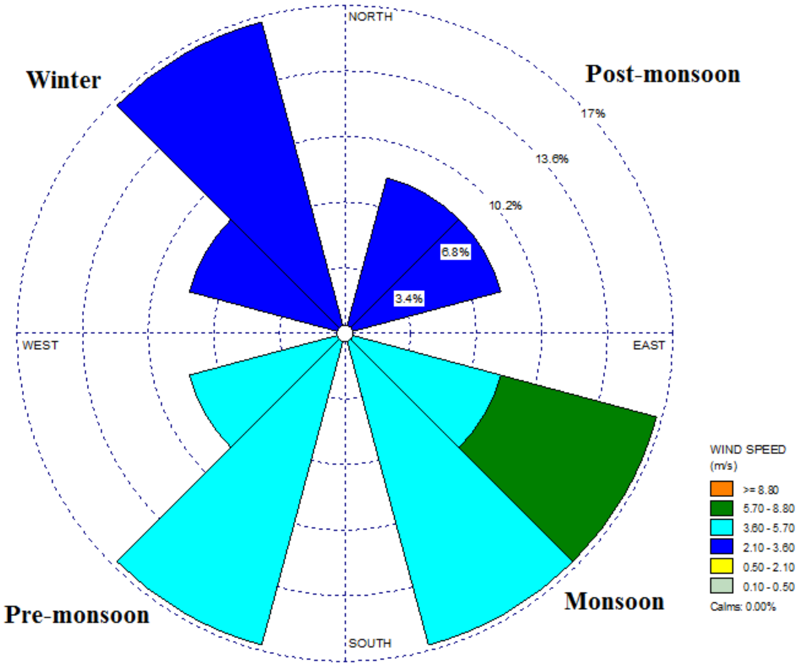

Figure 10. Wind Rose of Pre-monsoon, Monsoon, Post-monsoon and Winter Season

where q = quality rating; V = observed value of parameter; Vs = value recommended for that parameter.

If total 'n' no of parameters were considered for air monitoring, then the geometric mean of these 'n' number of quality ratings were calculated in the following way:

$$g = \text{anti}\ \log(\log a + \log b + \ldots\ldots\ldots \log x)/n \qquad (2)$$

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

3.8.1 Status of AQI Variation in Chittagong

Table 3 displays the monthly Air Quality Index (AQI), which was determined at the CAMS-6 Chittagong stations. In the research period from October 2017 to September 2018, the monthly AQI at the Chittagong station ranges from 07 to 460, correspondingly. Minimum and maximum AQI values were found to range from 11 to 258 in the post-monsoon season, 24 to 460 in the winter season, 12 to 344 in the pre-monsoon season, and 7 to 112 in the monsoon season.

3.8.2 AQI Variation in Different Seasons

According to Table 4, a monthly summary of calculated AQI values based on data from CAMS-6, Chittagong showed that during the pre-monsoon season average AQI value (223.66) indicate the air quality was very unhealthy categories, in monsoon season average AQI value (109.5) indicate the air quality was caution categories, in post-monsoon season average AQI value (194.5) indicate the air quality was unhealthy categories. The average AQI rating for the winter (317.33) shows extremely unfavorable categories of air quality. Because of the intensity of the rainfall, temperature, and wind speed, the pollution is more severe in the winter and less severe in the monsoon season. In all cases most frequent responsible pollutant was $PM_{2.5}$. In the absence of $PM_{2.5}$ sometimes found responsible pollutant PM_{10}.

4. CONCLUSIONS

Chittagong, Bangladesh's commercial hub is facing serious consequences for health as a result with an insufficiency of air quality. As Chittagong city (once a healthy and clean city in Bangladesh) contains largest sea port, three export processing zones,) has grown up to be a severe issue in recent decades due to its unplanned urbanization, road constructions, industrial pollutants and allied traffic on roads. A continuous air monitoring station (CAMS-6) measured the levels of the primary air pollutants (SO_2, NO_2, O_3, CO, $PM_{2.5}$, and PM_{10}) to determine their seasonal variations. In 2018, January saw the highest peak ($PM_{2.5}$= 93.5 μg/m^3, PM_{10}= 210 μg/m^3), and July and August saw the lowest concentrations ($PM_{2.5}$= 14.6 μg/m^3 and PM_{10}= 26.9 μg/m^3). While the concentration of O_3 (5.3 ppb) was recorded in the post-monsoon (October-November) of 2017, the average concentration of SO_2 showed the highest value (12.8 ppb) in the monsoon season (June-August) and the lowest value (3.2 ppb) in the winter season (December-February). Prior to and during the monsoon, NO_2 and CO concentrations were highest (64.9 ppb and 1.2 ppm, respectively), and during the monsoon, and pre-monsoon they were lowest (24.4 ppb

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

Seasons	Month of the Year	Average AQI Value	Minimum AQI Value	Maximum AQI Value	Seasonal Average
Post-monsoon	October, 2017	50.38	11	131	194.5
	November, 2017	131.06	44	258	
	December, 2017	128.22	24	188	
Winter	January, 2018	231.9	44	460	317.33
	February, 2018	209.21	143	304	
Pre-monsoon	March, 2018	164.48	70	344	223.66
	April, 2018	117.11	39	207	
	May, 2018	47.48	12	126	
	June, 2018	40.1	7	112	
Monsoon	July, 2018	34.16	14	60	109.5
	August, 2018	39.2	15	90	
	September, 2018	78.96	19	176	

Table 4. Approved Air Quality Index (AQI) for Bangladesh

Air Quality Index (AQI) Range	Category/Health Standard In English	In Bangla	Color
0-50	Good	Bhalo	Green
51-100	Moderate	-	Yellow Green
101-150	Caution	-	Yellow
151-200	Unhealthy	Ashasthykar	Orange
201-300	Very Unhealthy	Khub Ashasthykar	Red
301-500	Extremely Unhealthy	Ottanata Ashasthykar	Purple

(Source: CAMS-6)

and 0.6 ppm, respectively). The AQI values (223.6), (109.5), (194.5), and (317.3) indicate that the air quality during the pre-monsoon, monsoon, post-monsoon, and winter season was very unhealthy, cautious, unhealthy, and extremely unhealthy, respectively.

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