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Statistical evaluation of selected air quality parameters influenced by COVID-19 lockdown

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ABSTRACT

Air pollution has become a serious concern for its potential health hazard, however, often got less attention in developing countries, like Bangladesh. It is expected that worldwide lockdown due to COVID-19 widespread cause reduction in environmental pollution in particularly the air pollution: however, such changes have been different in different places. In Chittagong, a city scale lockdown came in force on 26 March 2020, a week after when first three cases of COVID-19 have been reported in Bangladesh. This study aims to statistically evaluate the effects of COVID-19 lockdown (26 March to 26 April 2020) on selected air quality pollutants and air quality index s. The daily average concentrations of air pollutants PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO of Chittagong city during COVID-19 lockdown were statistically evaluated and were compared with dry season data averaging over previous 8 years (2012 to 2019). During lockdown, except NO_2, all other pollutants studied showed statistically significant decreasing trend. During the COVID-19 shutdown notable reduction of 40%, 32% and 13% compared to the daily mean concentrations of these previous dry season were seen for $PM_{2.5}$, PM_{10} and NO_2, respectively. The improvement in air quality index value was found as 26% in comparison to the previous dry season due to less human activities in COVID-19 shutdown. The factor analysis showed that AQI in Chittagong city is largely influenced by PM_{10} and $PM_{2.5}$ during COVID-19 shutdown. The lesson learnt in this forced measure of lockdown is not surprising and unexpected. It is rather thought provoking for the decision makers to tradeoff the tangible air quality benefits with ongoing development strategies' that was often overlooked directly or indirectly.

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INTRODUCTION

Air pollution has become a critical threat to the environment as well as causes serious threat to health. About 80% people in urban areas are exposed to the air pollution exceeding the air quality standard value set by World Health Organization (WHO) and even 98% of cities in low-middle income countries and 56% in high income country do not meet the WHO guidelines (WHO, 2016). More than 4.2 million estimated people die worldwide every year due to exposure of ambient (outdoor) air pollution by cardiac arrest, brain stroke, cancer and different types of chronic respiratory diseases (WHO, 2016). In relation to global burden of disease, air pollution is found one of the top ten killers in the world while it ranked sixth in South Asia. With the development target, rapid growth in urbanization and industrialization compromising environmental health, Bangladesh is not an exception like other urban centers. A few studies reported that the concentration of air pollutants remain below the Bangladesh National Ambient Air Quality Standard (BNAAQS) during the wet periods whereas far above the standard values during the rest of the year especially in dry periods (Zahangir *et al.,* 2001; Motalib and Lasco, 2015; Rahman and Al-Muyeed, 2016). In this line, Mahmood *et al.* (2019) noted that vehicular emissions and construction activities are primarily responsible for suspended particulate matter (PM) that further increased air quality index (AQI) harshly. The AQI values often reached to several folds higher than limit values in Dhaka and in Chittagong, the capital city and the financial capital city of Bangladesh, respectively, that ranked within top ten world largest polluting cities during the dry period (e.g. November to April) due to improper actions against polluters, such as brick kilns, road traffic sectors, industrial emissions and construction and development activities etc. (Begum and Hopke, 2018; CASE, 2019b). The shift in policy of leaded free fuel in vehicle sector, increased height of industrial chimney (particularly for brick kilns, steel mills and cement industries in Chittagong) and others related actions by government, hardly see abatement in the concentrations of air pollutants in major cities i.e. Dhaka and Chittagong. It is harsh reality in developing countries where air pollution is often neglected overlooking its large threat to human and aquatic lives and, hence unquantified and unexplored. This situation is continued until the forced measures of country wide lockdown has been imposed since 16 March 2020 due to the first three case of COVID-19 infection recorded on March 8, 2020 in Bangladesh (IEDCR, 2020). Government of Bangladesh (GoB) declared an almost 10 days COVID-19 complete shutdown to be executed from 26 March, 2020 to control the spreading and to maintain the social distance and at later it continued in many phases (Shawon, 2020) until 26 April, 2020 when authority allows the factories and other economic sectors to be reopened in limited scale maintaining health regulations set by the GoB. Nevertheless, that limited opening causes increased in human activities as before shutdown (Haque and Ahamad, 2020). The forced measures of complete lockdown appear as self-cleansing period for the environment, and now can be considered blessing in disguise as noted by Tobías *et al.,* (2020) highlighting significant decrease in nitrogen dioxide (NO_2) in China during quarantine (February 10 - 25) and improvement in air quality in Barcelona, Spain. Furthermore, a study in Almaty, Kazakhstan by Kerimray *et al.,* (2020), reported $PM_{2.5}$, NO_2 and CO concentrations were decreased by 21%, 35% and 49%, respectively, during lockdown period. Due to COVID-19 lockdown, human activities have reduced up to 90% due to this COVID-19 pandemic and environmental pollution reduced about 30% in Spain, USA, Italy and Wuhan (Muhammad *et al.,* 2020).

Many researchers have concluded studies on impact of COVID-19 lockdown on environmental pollution level especially air pollution in many major cities of the world. The concentration of $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 in the major three cities of central China have reduced 30.1%, 40.5%, 33.4%, 27.9% and 61.4%, respectively, during COVID-19 lockdown, and hence Air Quality Index (AQI) reduced 32.2%, 27.7% and 14.9% as compared with the concentrations during 2017-19 (Xu *et al*., 2020). Moreover, Sharma *et al*., (2020) stated that, maximum reduction happens in the case of $PM_{2.5}$ in most of the regions in India. Moreover, the concentration of $PM_{2.5}$, PM_{10}, CO, and NO_2 declined by 41%, 52% and 28%, respectively, in six megacities of India (Jain and Sharma, 2020). Moreover, similar declined trend found in the concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO, and NO_2 in major cities of Bazil, Chaina, Spain and Morocco but an increasing trend found in the concentration of Ozone (O_3) in all cases (Dantas *et al*., 2020; Otmani *et al*., 2020; Tobías *et al*., 2020; Xu *et al*., 2020). They also mentioned that that the changes in air quality in different cities around the world may not follow the similar trend, and hence, requires local study to understand the pattern of changes. As Chittagong city contains largest sea port, three export processing zones, and industrial hubs in Bangladesh, the air pollution in Chittagong (once a healthy and clean city in Bangladesh) has become serious issue in recent years due to its unplanned urbanization, growth of housing, road constructions, drainage infrastructures, industrial emissions and associated traffic on roads. The COVID-19 pandemic restricted entry and exit from the city and allowing little to no movement for its residents and public and private vehicles (except emergency vehicles declared by the Govt. of Bangladesh) since 17 March, 2020, and this provide a room for improving its environmental health keeping people at home. This study therefore, aims to evaluate the impressions of COVID-19 lockdown settings on the air quality. The investigation of the changes in air quality pollutants, such as PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO before and during the period of COVID-19 lockdown (March to April 2020) has been carried out in Chittagong, Bangladesh using statistical analyses. The conditions of air quality evaluated during COVID-19 lockdown and pre-lockdown period may be helpful for decision and policy makers to address air pollution control measures ahead.

MATERIALS AND METHODS

Daily average concentrations of air pollutants PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO for Chittagong during COVID-19 lockdown period (March to April, 2020) along with previous monthly data for the aforesaid pollutants from 2012 to 2019 were collected from Department of Environment (DoE) that measured data daily basis from its measuring station located in Agrabad, Chittagong (22.32^{0}N and 91.8^{0}E) set under the Clean Air and Sustainable Environment (CASE) Project. Chittagong city with 22.3569^{0}N and 91.7832^{0}E is situated in the southern part of Bangladesh near the Bay of Bengal with tropical monsoon climate (Fig. 1). The temperature in the month of March and

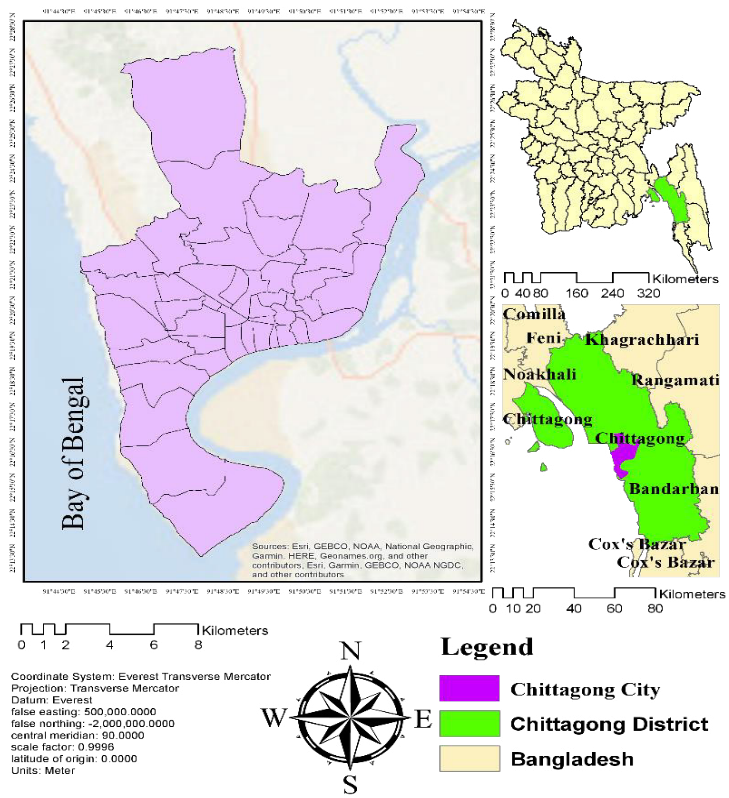

Fig. 1: Geographic location of the study area showing Chittagong City in Bangladesh

April is found to vary between 19⁰C – 33.5⁰C with an average of 26.0⁰C and 28.1⁰C, respectively, during 1990-2019 in Chittagong. The average rainfall of Chittagong is 2990 mm which is moderately high than other locations in Bangladesh. Mostly rainfall occurs between June to October. In July, the precipitation reaches its peak, with an average of 721 mm. The city typically receives 48.1 mm and 120.1mm rainfall in March and April. However, during the studied lockdown period (26 March to 26 April 2020), city did not receive any rainfall.

The data of pollutants before COVID-19 years (2012 to 2019) were further divided into dry (generally November to February) and wet season (March to October) for comparing the effects of before and after COVID-19 shutdown periods respectively as the months March and April are the transition periods between dry and wet season. The limit value and/or allowable concentrations of the air pollutants were collected from Bangladesh National Ambient Air Quality Standard (BNAAQS) set by Department of Environment (DoE) (CASE, 2019a). As, the AQI appears to be is a good communication vehicle to describe the ambient air quality with health concern, in this study the AQI values were estimated using Eq. 1 as reported in Environmental Protection Agencies (EPA) regulations (EPA, 2006). Typically lower the value of AQI, the healthier the air quality environments.

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}\left(C_p - BP_{Lo}\right) + I_{Lo} \qquad (1)$$

Where, *Ip=The index value for pollutant p*, *Cp=The concentration of pollutant p*, BP_{Hi}=*The Breakpoint ≥ Cp*, BP_{Lo}=*The Breakpoint ≤Cp*, I_{Hi}=*The AQI value Corresponding* BP_{Hi} and I_{Lo}=*The AQI value Corresponding* BP_{Lo}.

Trend analysis for each of the air pollutants as well as for AQI for the Lockdown period due to COVID-19 data has been carried out. Furthermore, Non-parametric Mann–Kendall test has been performed along with the Sen's slope method to detect the trends and their respective magnitudes of air pollutants. The confidence intervals for the tests were considered as 99.99% (***), 99% (**), 95% (*) and 90 (+) ($p < 0.001$, $p < 0.01$, $p < 0.05$, $p < 0.10$) for the accepted changes (if any) for positive or negative trend. Details of Mann-Kendall test can be found in Sneyers (1990). Thereafter, the Principle Component Analysis (PCA) for the collected data were carried out using statistical software SPSS Version 20 to identify the group of the variables and their influences on AQI and overall improvement in air quality. In PCA, the factor loadings for each of the member of air pollutants data set has been taken into consideration

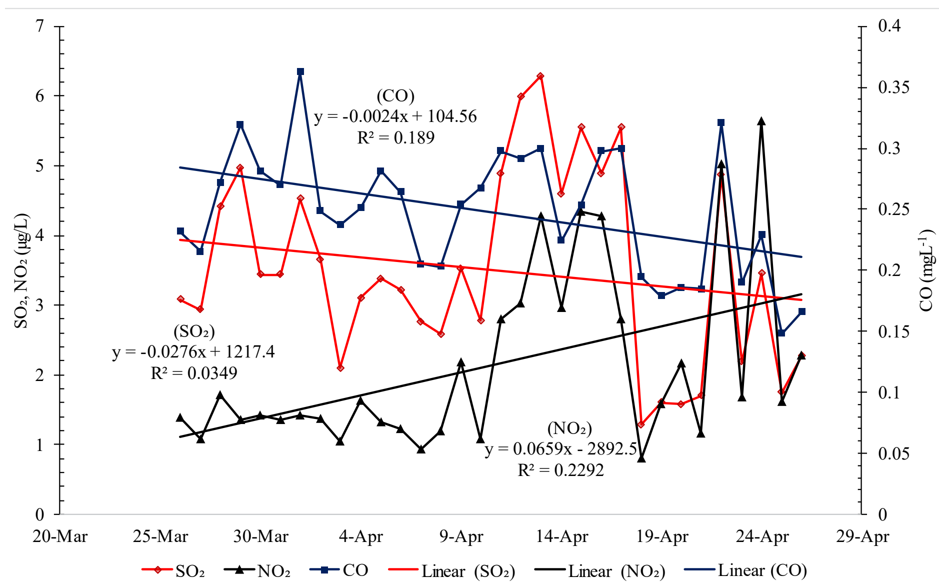

Fig. 2: Daily variation and trend of gaseous air pollutants during COVID-19 lockdown period of Chittagong

for clustering, and hence, grouping of air pollutants whereas numbers of the cluster groups are decided based on the variations shown by the principle components (Mahapatra *et al.*, 2012).

RESULTS AND DISCUSSIONS

Trend analysis of air pollutants

Daily variations for gaseous pollutants CO, SO_2 and NO_2, and particulate pollutants PM10 and PM2.5 along with AQI, and their respective trends during COVID-19 lockdown period (March to April 2020) were analyzed and shown in Figs. 2 and 3, respectively. In addition, Mann-Kandel test for statistical significance of the trends and the daily increase or decrease magnitude rate using Sen's slope were performed and presented in Table 1. As seen in Fig. 2, the variations of gaseous pollutants result both ups and down spikes with decreasing trend for CO and SO_2 and increasing trend for NO_2. While decreasing trends of CO and SO_2 is expected and reasonable due to lockdown, the increasing trend of NO_2 is rather unexpected.

Within this context, Fig. 3 demonstrates declined trends of the PM_{10} and $PM_{2.5}$ along with AQI illustrating the blessing of forced shutdown of industries, vehicles, construction activities that further make room for environmental adjustment of pollution. R-squared (R^2) value for PM_{10} and $PM_{2.5}$ and AQI found 0.46, 0.52 and 0.49, respectively, (Fig. 2) while that for CO, SO_2 and NO_2 are found as 0.19, 0.03 and 0.23, respectively (Fig. 1). Although R^2 reported here are poor to fair due to limited data of a month during studied lockdown period, but these are found satisfactory and consistent with studies elsewhere (Begum and Hopke, 2018; Kerimray *et al.*, 2020). The results of statistical significance of the trends as obtained in Figs. 2 and 3, and their respective rate are presented in Table 1. As seen in Table 1, it has been perceived that the particulate pollutants ($PM_{2.5}$ and PM_{10}) and AQI exhibit very strong statistical significance of their decreasing trend at 99.99%

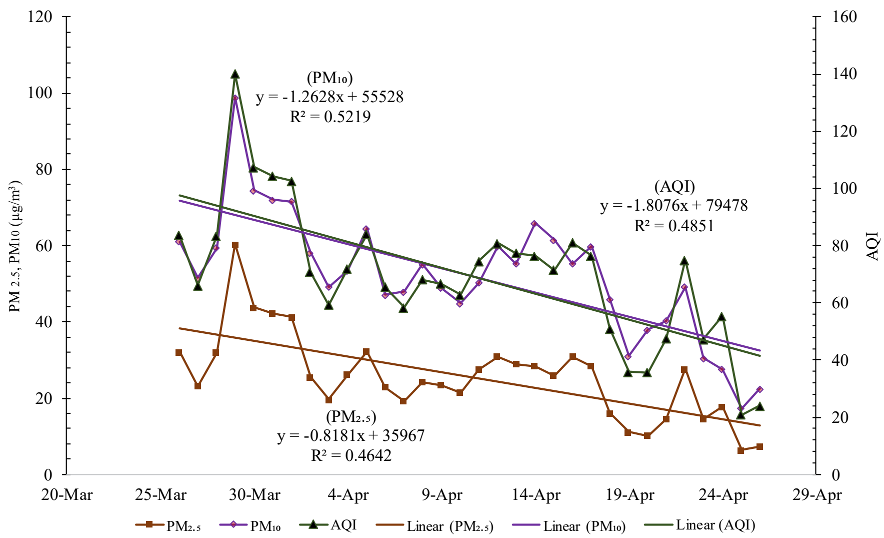

Fig. 3: Daily variation and trend of particulate pollutants and AQI during COVID-19 lockdown period of Chittagong

Table 1: Mann-Kandle and Sen's slope analysis of air pollutants for COVID-19 lockdown period

Parameters	CO	SO_2	NO_2	$PM_{2.5}$	PM_{10}	AQI
Test Z	-1.99	-0.88	2.19	-3.78	-4.14	-3.76
Significance strength	*		*	***	***	***
Q	-0.002	-0.031	0.037	-0.749	-1.174	-1.604

***, **, * indicates 99.99%, 99% and 95% confidence level confidence level ($p < 0.001$), and that for CO and NO_2 are found at 95% confidence level ($p < 0.05$), while SO_2 shows no significance.

Sen's Slope estimator (Q) for the rate of trends of both $PM_{2.5}$ and PM_{10} are found as -0.749 µgm^{-3}day^{-1} and -1.174 µgm^{-3}day^{-1}, respectively, while that for the CO and SO_2 result -0.002 mg/L/day and -0.031 µg/L/day, respectively, and in contrast NO_2 shows increasing trend at a rate 0.037 µg/L/day although the change is not significant. The value of AQI also shows a significant decreasing trend at a rate -1.604/day with higher significant level.

Comparison of pollution level during COVID-19 period with dry and wet season

Concentration of air pollutants during COVID-19 shutdown are compared as shown in Figs. 4 and 5 with the average concentration found during dry and wet season between 2012 to 2019 for comparing the effects of COVID-19 shutdown as March and April month are the transitional month between dry and wet periods. However, concentration of air pollutants during COVID-19 shutdown found significantly lower than the concentration during dry and wet season. The concentrations of CO, SO_2 and NO_2 found 86%, 56% and 93% lower (Fig. 4) than the wet period. Moreover, it has been found the concentrations are 83%, 41%, 85% lower than the dry period. Lower concentration found in the case of SO_2 among the other gaseous air pollutant for both dry and wet periods. However, concentration of gaseous air pollutants is higher in dry season as compared with wet season although concentrations are within the BNAAQS limits for both seasons as well as during COVID-19 shutdown period also. Similar reduction for gaseous air pollutants have been reported in Kazakhstan USA, Italy, Brazil and Spain (Kerimray *et al.*, 2020; Muhammad *et al.*, 2020).

Whereas similar scenario found for the particulate matter (Fig. 5) but the concentrations level exceeds the BNAAQS limits during dry season. Moreover, the concentrations of $PM_{2.5}$ and PM_{10} during COVID-19 shutdown significantly lower by 79% and 76% as compared with dry season. However, the rate is found 36% and 37% much lower for $PM_{2.5}$and PM_{10} in wet period which is about half as compared with dry season. Almost similar trend found for both particulate matter. In the case of AQI, the value is 72% and 27% lower than that of dry and wet season, respectively. During the dry period, AQI mostly exceeds the standard limit (>100) but in COVID-19 lockdown period the value found about 70 which satisfies the BNAAQS limit.

Descriptive statistics of air quality pollutants and AQI

Table 2 presents the descriptive statistics of the pollutants investigate under this study along with AQI. The permissible value set by the GoB is also presented in the table. The previous year data were analyzed dividing into two season such as

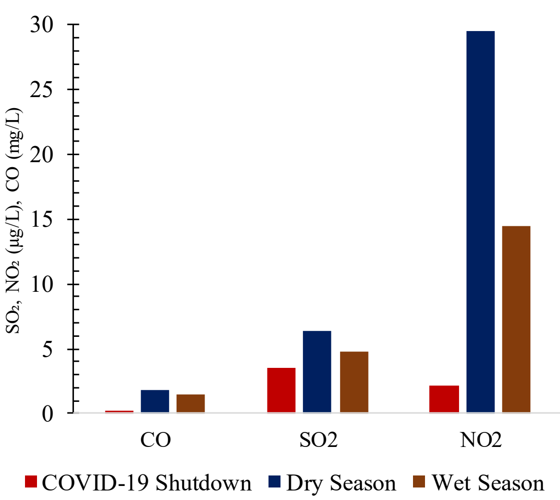

Fig. 4: Comparison of pollution level COVID-19 shutdown with dry and wet season for gaseous pollutants

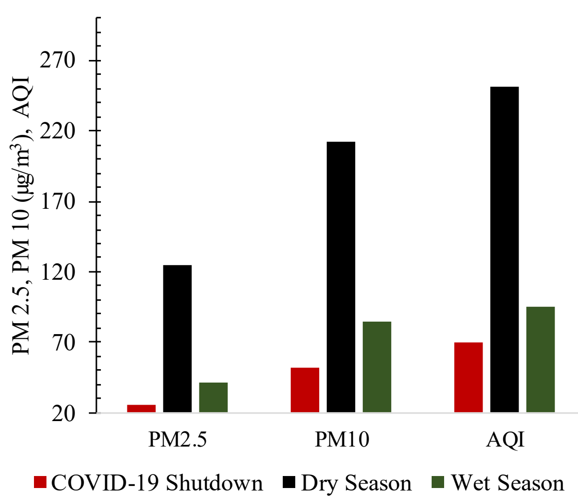

Fig. 5: Comparison of pollution level during COVID-19 shutdown with dry and wet season for particulate matters

dry (November to April) and wet (May to October) considering the fact that air quality is highly affected by the meteorological changes in different seasons where the dry period with little or no rain is found as most harmful for human and aquatic health concern.

As seen in Table 2, the mean concentrations the gaseous pollutants (i.e. CO, SO_2 and NO_2) in air, irrespective of the seasons, are found well below their respective standards set by the GoB. However, in few cases NO_2 concentrations exceed the permissible value mainly in dry season (based on the maximum concentrations). Nevertheless, based on the mean values of CO, SO_2 and NO_2 in previous dry seasons and that with COVID-19 lockdown period, the concentrations were found 7, 2 and 14 times higher, respectively. Taking particulate matter in consideration, it has been seen that the mean concentrations of PM_{10} and $PM_{2.5}$ were significantly higher compared to their respective standard concentrations in dry season (Table 2) and, in comparison to COVID-19 lockdown period these are as high as 4 and 5 times, respectively. Furthermore, from Table 2, the mean vale of the AQI based on previous four years' dry season reached to 251 and that is approximately 2.5 and 4 times higher than the allowable AQI of 100 set by the Government of Bangladesh (100) and AQI mean of 69 estimated during COVID-19 lockdown. However, considering the maximum value in dry season the AQI reached to 440 reflecting extremely unhealthy and that for wet season with AQI of 247 represent unhealthy condition, while during COVID-19 maximum AQI of 140 illustrate condition with cautions for city dwellers. As the air quality pollutants discussed here such as, PM_{10}, $PM_{2.5}$, CO, SO_2 and NO_2 emissions in the city are primarily linked to the road traffic environment, such as motor vehicle exhaust along with industrial emission, the findings reflecting the day to day

Table 2: Descriptive Statistics of air pollutants during COVID lockdown (March to April 2020) and for previous years 2012 to 2019 of Chittagong City, Bangladesh

Parameters	Period	Limit value*	Min.	Max.	Mean	S.D.	CV
CO	COVID-19**	35 mg/L	0.15	0.36	0.25	0.05	0.21
	Dry Season		0.86	4.42	1.77	0.77	0.49
	Wet Season		1.15	1.15	1.43	0.22	0.81
SO_2	COVID-19**	140 µg/L	1.29	6.28	3.51	1.39	0.39
	Dry Season		5.54	20.40	6.42	0.20	0.86
	Wet Season		4.05	16.08	4.76	0.88	0.85
NO_2	COVID-19**	53 µg/L	0.80	5.65	2.13	1.29	0.62
	Dry Season		19.09	80.50	29.51	3.95	0.65
	Wet Season		10.93	62.07	14.43	2.33	0.76
$PM_{2.5}$	COVID-19**	65 µg/m^3	6.43	60.40	25.50	11.26	0.44
	Dry Season		25.00	177.95	124.52	75.90	0.20
	Wet Season		25.42	106.00	41.16	13.10	0.62
PM_{10}	COVID-19**	150 µg/m^3	17.35	98.90	52.13	16.40	0.32
	Dry Season		40.71	289.00	212.33	129.00	0.19
	Wet Season		51.80	204.00	85.10	0.06	0.61
AQI	COVID-19**	100	21	140	69	24.35	0.35
	Dry Season		88	440	251	130.16	0.35
	Wet Season		56	247	95	24.16	0.59

* Bangladesh National Ambient Air Quality Standard (BNAAQS)
**Lockdown Period considered (March to April 2020)

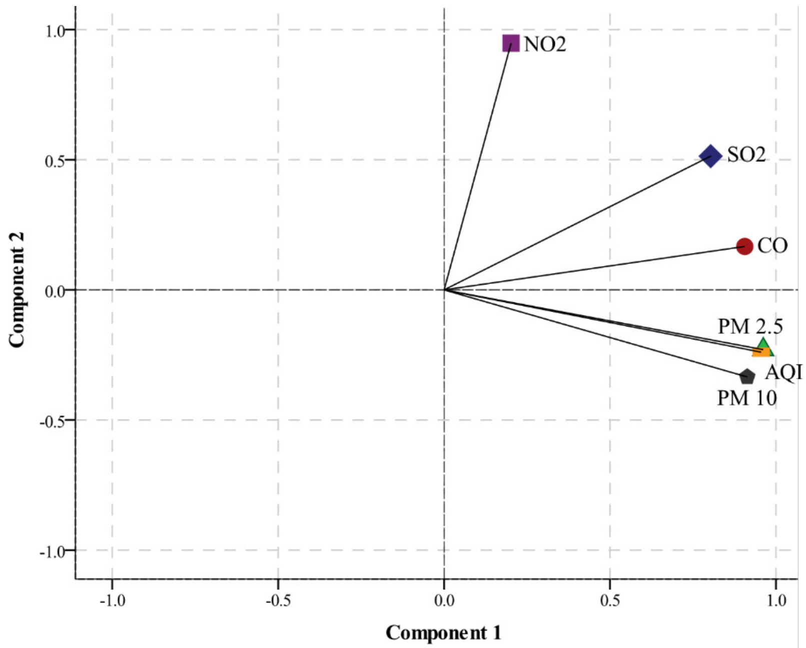

Fig. 6: Distribution of air pollutants using in two components by Principal component analysis (PCA)

scenario of air pollution when the roads were seen heavily trafficked with trucks and lorries to transport goods from the sea port to elsewhere in the country; the passenger vehicles movement (large number of auto-rickshaws – three stroke engine taxis) create a chaotic situation on roads and with its stop and start maneuvering pattern due to traffic jams and hilly nature of the area. Furthermore, steel and cement industries and brick kilns' emission further boosted that magnitude in the immediate surroundings as well as the overall air quality of Chittagong. In this line, the typical road cleaning by manual dry sweeping also exposed finer fraction resuspended to air and contribute to the enriched particulate matter. The uncontrolled infrastructures construction and maintenance activities around the city were also seen to be the substantial contributor of the particulate matter during dry season. On the other hand, during COVID-19 lockdown, the scenario was just opposite to what explain now with empty road (exceptionally low traffic volume of emergency vehicles) and shut down of the industries allows room for self-cleansing of air quality pollutants greatly. The lesson learnt in this forced measure of lockdown is not surprising and unexpected rather thought provoking for the decision makers to tradeoff the tangible air quality benefits with ongoing development strategies' that was often overlooked directly or indirectly. As for example, a good decision to introduce cleaner fuel compressed natural gas (CNG) to the vehicle sector helps to reduce gaseous pollutants from the exhaust emission. The more initiatives like this should be taken to keep pollution within the allowable limits to help comfortable livelihood for all living things.

Factor analysis of air pollutants

Fig. 6 presents the cluster of pollutants studied in this study using Principal Component Analysis (PCA). Two major cluster (PC1 and PC2) have been found for 6 variables based on their factor loading. Particulate matter $PM_{2.5}$, PM_{10} and AQI belong to PC1, whereas the gaseous pollutants SO_2, NO_2, CO belong to PC2. It is seen that the AQI is mostly biased by the $PM_{2.5}$ and PM_{10} rather than gaseous pollutants, signifying the fact that air is heavily enriched with fine particulate matter derived from the road traffic environment and its poor maintenance, manual street sweeping exposing finer dust, industrial emissions particularly from clay burn brick kilns along with from massive uncontrolled construction and infrastructure development project sites around the city. The significant enrichment of particulate pollutants in air not only creates a dust smog and gusty weather in dry season but also pose a serious health risk for younger and elderly population in the city.

CONCLUSION

Air quality in Chittagong city has been analyzed statistically for the period of 2012 to 2019 and during COVID-19 lockdown period (26 March to 26 April 2020), discussed and compared. It has been seen that every year in dry season (November to February) air environment of the city turns to unhealthy (AQI > 150) to extremely unhealthy conditions (AQI> 200) enriched significantly by the $PM_{2.5}$ and PM_{10} concentrations rather than with gaseous pollutants compared to the air quality standard set by the government of Bangladesh. The PCA analysis further confirms the association of AQI with the $PM_{2.5}$ and PM_{10}. The air environment in wet season found better than dry season. In a special circumstance of COVID-19 lockdown, a substantial reduction of gaseous and particulate pollutants was found. The more notably the reduction of $PM_{2.5}$, PM_{10} and NO_2 were 40%, 32% and 13% compared to the mean concentrations of these for previous 8 years dry season. Except NO_2 other pollutants showed decreasing trends during COVID-19 lockdown and similar trend was revealed for AQI. Except SO_2 other pollutants exhibit statistically significant changes over the lockdown period. The lesson learnt in this forced measure of lockdown is not surprising and unexpected rather thought provoking for the decision makers to tradeoff the tangible air quality benefits with ongoing development strategies' that was often overlooked directly or indirectly. As for example, a good decision to introduce cleaner fuel compressed natural gas (CNG) to the vehicle sector helps to reduce gaseous pollutants from the exhaust emission. Such initiatives will lead to keep pollutants level within the allowable standards limits and will help improve the peoples' livelihood as well as the conditions of the ecological system.

AUTHOR CONTRIBUTIONS

M.H. Masum has performed the paper conceptualization, methodology, investigation, formal analysis, writing the draft. S.K. Pal has done the conceptualization, methodology, writing, review and editing, visualization, project administration and supervision.

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ABBREBIATION

AQI	Air Quality Index
CASE	Clean Air and Sustainable Environment (CASE)
CNG	Compressed Natural Gas
CO	Carbon mono oxide
DoE	Department of Environment
EPA	Environmental Protection Agencies
GoB	Government of Bangladesh
mg/L	Milligram per liter
mg/L/d	Milligram per liter per day
NO_2	Nitrogen di Oxide
O_3	Ozone
PCA	Principal Component Analysis
$PM_{2.5}$	Particulate Matter (2.5)
PM_{10}	Particulate Matter (10)
SO_2	Sulfur di Oxide
WHO	World Health Organization
EPA	Environmental Protection Agencies
µg/L	Microgram per liter
$\mu g/m^3$	Microgram per meter cube
µg/L/d	Microgram per liter per day
$\mu g/m^3/d$	Microgram per meter cube per day

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