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COVID-19 Induced Lockdown Consequences on Air Quality and Economy - A Case Study of Bangladesh

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Abstract The present study involves the investigation of air quality of Dhaka city, Bangladesh, before and during the periods of lockdown imposed to reduce the spread of a novel coronavirus (*COVID-19*) and comparison of data in corresponding periods of two previous years. Further, the consequences of *COVID-19* in terms of economic disruptions were also studied. The accelerated and vast diffusion of *COVID-19* in Dhaka has a high association with air pollution compared to the other cities of Bangladesh. Air pollution can be considered as an important determinant in the *COVID-19* crisis. It was found that the mean air quality index (AQI) in Dhaka before lockdown in March in 2020 was found to be 4.82% and 5.30% lower compared to the corresponding period in 2018 and 2019, respectively. On the other hand, the average AQI during the lockdown in 2020 was found to be 9.57% and 16.74% lower respectively compared to the same period in 2018 and 2019. A significant negative correlation was found between AQI and rainfall ($p<0.01$) during the period of lockdown. Indeed, Dhaka city had better air quality during the lockdown but it was prognosticated that the remittance would fall by about 22% and GDP would plunge to a range between 2% and 3% in 2020 due to *COVID-19*.

Keywords: *air pollution, Bangladesh, COVID-19, economic consequences, health effects, lockdown*

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1. Introduction

Coronavirus (*COVID-19*), formerly known as 2019-nCOV, is a novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) which belongs to 2b beta-coronavirus of the subgenus sarbecovirus, Orthocoronaviridae subfamilies [1,2]. This virus was first reported in December 2019 as an "unknown viral pneumonia", which transmitted to humans through unknown intermediate host from a seafood market in Wuhan city of China [1,3,4]. By the 16th of May 2020, a total number of 4,434,653 infected persons were identified and 302,169 deaths were reported globally because of *COVID-19* [5]. Outside China, the first infected case was reported in Thailand on 13th January 2020 and as of 13th May 2020, this infection has been spread over 215 countries [6]. The worldwide scenario of *COVID-19* is shown in Figure 1. The first *COVID-19* infected case in Bangladesh was reported on 08th March 2020 [7]. Bangladesh, a country of South Asia, has an area of 147,570 sq km [8] and a total population of 160 million [9]. Because of the very high density of the population, Bangladesh is at high risk of *COVID -19* outbreak all over the country as this virus mainly spread by human to human contact through the infected person's coughs and sneeze producing micro-droplets.

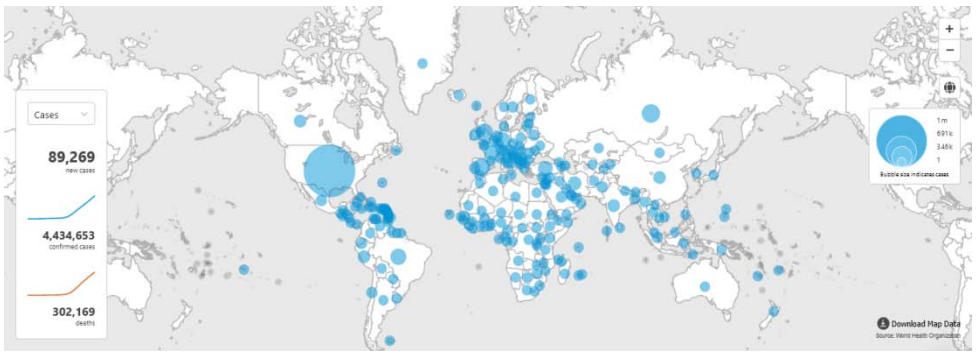

Figure 1. Worldwide scenario of *COVID-19* as of 16th of May 2020 [5]

The World Health Organization (WHO) declared *COVID-19* a pandemic mentioning the global spread of this novel virus [3]. *COVID-19* has a great impact on the global economy, culture, and health. Likewise, its challenges on the national economy can never be underemphasized. To control the spread of this infection through maintaining social distancing, the Government of Bangladesh imposed a nationwide lockdown on 26th March 2020, which was gradually extended until 5th May 2020. Because of this lockdown, the number of vehicles running on the street, industrial and anthropogenic activities in Bangladesh decreased markedly resulting in reduced emissions of harmful substances in the atmosphere.

Emission of hazardous substances into the atmosphere that is harmful to human health and the planet as a whole is referred to as air pollution. Air can be polluted from natural and anthropogenic sources including emissions from vegetation, from the biomass of the ocean, volcanic gas, combustion of liquid and solid-fuel (diesel, petrol, coal, lignite, heavy oil and biomass) for energy production, other industrial activities (building, mining, manufacture of cement, smelting) and the re-suspension of dust in arid areas such as deserts [10,11]. These sources lead to both indoor and outdoor forms of air pollution. However, as air moves from inside buildings to the outside, both indoor and outdoor air pollution can contribute to each other and vice versa [12]. Dhaka, the capital of Bangladesh, is the largest and is the most important city in the country concerning economics, politics, and culture. Because of the high population density, traffic congestion, industrial and commercial activities, Dhaka was stressed with air pollution and ranked as the most polluted city in the world based on air quality index (AQI) [13].

AQI is based on the levels of particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2) and ozone (O_3) in the atmosphere. Higher the levels of these toxins in the air, the upper the values of AQI, and ultimately, the greater the levels of air pollution [14]. The main driving activities of air pollution in Dhaka are vehicles running on fuel containing high levels of sulfur, illegal brick kilns, construction works, industrial activities, etc. in and around Dhaka city. The PM affects more people than any other pollutant. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust, and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air.

The *COVID-19* is causing widespread concerns as the number of infections and deaths to rise across the world. It is threatening the health and lives of millions of people worldwide. The health effects of the *COVID-19* range from mild or uncomplicated illness to acute respiratory disease syndrome (ARDS) and multi-organ damages, including acute kidney and cardiac injury [15]. However, the adverse impacts of *COVID-19* may be quite large when considering aspects of economic challenges in addition to health effects. The outbreak of *COVID-19* pandemic has critically disrupted social, economic, political, religious and financial structures. The lockdown measures to prevent the transmission of *COVID-19* have significant impacts on financial markets, manufacturing industries, tourism, and travel. Besides, it adversely affects the economy of self-employed daily wage earners or part-time workers. In Bangladesh, remittance plays an important role in socio-economic development. The outbreak of *COVID-19* all over the world is making it hard for employees working outside Bangladesh to contribute to foreign remittance resulting in an adverse impact on the economic growth of Bangladesh. The remittances of low and middle-income countries (LMICs) are projected to fall by 19.7% aggravating the life and livelihoods of the millions of people as a result thereof [16].

Considering the global problems *COVID-19* pandemic and problems of air pollution in Dhaka city, the objectives of this research were to study the levels of air pollution and related meteorological parameters in Dhaka city, Bangladesh before and during the lockdown of this year with that of the previous two years i.e., 2018 and 2019, and also to observe consequences on immediate and forthcoming economy of Bangladesh due to the impact of *COVID-19* induced shutdown of major commercial and industrial activities. In addition, this study showed the scenario of infection and death tolls in Bangladesh caused by this virus. Thus, this research will give an insight on *COVID-19* induced air pollution trends, human health effects and prospective economic consequences of Bangladesh.

2. Material and Methods

2.1. Study Area

Dhaka, the capital and the largest city of Bangladesh, has an area of 1497.17 sq km and lies between 23°53' and 24°06' North latitudes and in between 90°01' and 90°37' East longitudes. It is bounded Narayanganj district on the east, Manikganj and Rajbari districts on the west, Gazipur and Tangail districts on the north and Munshiganj district on the south [8]. The urban area is located on the northern bank of the Buriganga River and covers an area of 400 sq km [17]. This city is the center of the culture and economy which contributes to more than 35% of the total economy of the country. The major commercial areas of the city include Motijheel, Dilkhusha, Mohakhali, Kawran Bazar, Gulshan, and Banani, while the main industrial areas include Tejgaon and Hazaribagh. More than 7000 industries are situated mostly in three main areas of the Hazaribagh, Tejgaon, and Dhaka-Narayanganj-Demra dam areas in this urban city [18]. About 80% of the total garment factories are located in Dhaka city which contributes to the highest foreign exchange earning of the country. A wide range of transport systems are available in Dhaka city including private cars, trucks, and auto-rickshaws for movement of people and carrying of goods. Besides, intra- and intercity public bus services are the major mode of transport for the movement of a vast population. The rush movement of all types of transport in Dhaka city is responsible for traffic congestion as well as air pollution. The location of the study area is shown in Figure 2.

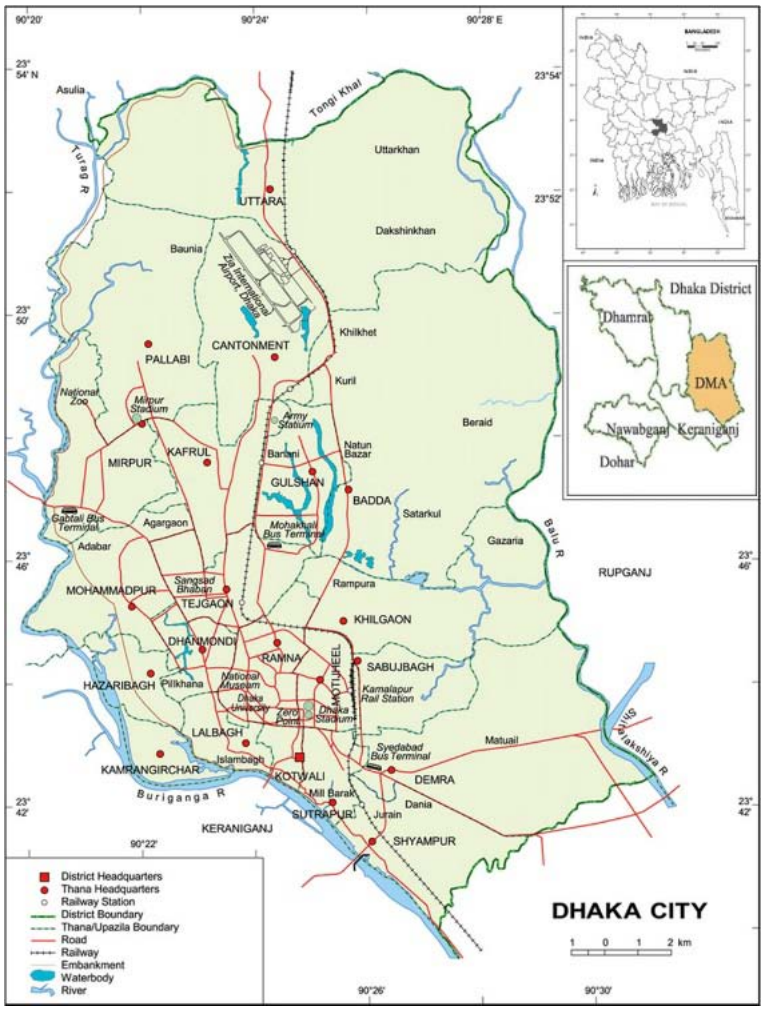

Figure 2. Map of the study area [8]

Table 1. Approved Air Quality Index (AQI) for Bangladesh [14]

Air quality index (AQI) range	Air pollution level	Health Implication
0-50	Good	Air quality is considered satisfactory with little or no risk of air pollution.
51-100	Moderate	Air quality is acceptable though pollution level makes concern for a group of people who are sensitive to air pollution.
101-150	Caution	Members of sensitive groups may have health effects, and the general public is not likely to be affected.
151-200	Unhealthy	Everyone may experience health hazards, and sensitive peoples may experience more serious health effects.
201-300	Very unhealthy	The entire population may experience more serious health effects.
301-500	Extremely unhealthy	Everyone is likely to be affected by more serious health effects.

2.2. Data Collection and Analysis

The present study was conducted from March to May 2020 considering multi-parameter data relating to air quality before and during the *COVID-19* induced lockdown. As such, the duration of the study was considered from the first day of March to the fifth day of May in 2020. The AQI data were obtained from air quality historical data measured by Dhaka US Consulate [19]. Other weather parameters related to AQI such as temperature (°C), rainfall (mm), humidity (%), and cloud (%) data during these periods were obtained from World Weather Online [20]. All the meteorological parameters during the above-mentioned study period in the years 2018 and 2019 were also compared to the present year.

The AQI data were categorized from good to extremely unhealthy as recommended by the Ministry of Environment and Forests, Government of the Peoples Republic of Bangladesh (Table 1). The data were analyzed by Microsoft Excel (version 2013) and statistical packages for social sciences (SPSS 16). Pearson's correlation coefficient ($p<0.05$) was used to examine the statistical significance of the differences in the mean AQI and meteorological parameters relating to air quality before and during the *COVID-19* induced lockdown among the month of March to May of the years 2020, 2019 and 2018. Basic statistics were used to study tendencies (mean) and the variability (standard deviation SD, coefficient of variation CV, minimum, maximum and median) of the AQI and meteorological parameters.

The total number of infected cases as well as active and death numbers in Bangladesh were collected from the website of Institute of Epidemiology, Disease Control, and Research [7]. The mortality rate caused by *COVID-19* was calculated by using the formula [4].

$$Mortality\ rate = \frac{Cumulative\ current\ total\ death}{Current\ conformed\ cases} \times 100.$$

3. Results

3.1. *COVID-19* Scenario in Bangladesh

Figure 3 shows infected and death cases in Bangladesh from the first day of *COVID-19* case identification to 5th May 2020 (till last day of nationwide lockdown). The first infected case was identified on 8th March 2020. A total of 3 persons were identified in the first day and the cumulative infected case crossed 10,000 in the first week of May 2020. However, the total number of confirmed cases at the final stage of manuscript preparation (16th May 2020) stood to 20,995 and the death tolls increased to 314. From Figure 3, it was clear that the number of confirmed cases was parallel up to 23 days after the first identification and the number increased significantly from the beginning of April 2020. The global fatality rate considering the total confirmed cases and cumulative death as of 5th May 2020 were compared with Bangladesh as well as other South-east Asian countries (Figure 4). The highest mortality rate in Bangladesh was found to be 11.43% on 4th April 2020 whereas the lowest mortality rate of 1.50% was observed at the time of final preparation of the manuscript (16th May 2020).

Figure 5 shows the distribution of infected and death cases in terms of age and sex. From the Figure, it was evident that 68% of all confirmed cases were between 21 and 50 years old, followed by 21% at the age group 51 years and above, while the age group below 20 years represented only 11%. The death due to *COVID-19* was observed to be 42% among people aged over 60 years followed by 27% among the age group between 51 and 60 years. On the other hand, in terms of sex, of all the confirmed cases, 68% were male and 32% were female, while, 73% death was reported in males and 27% in females.

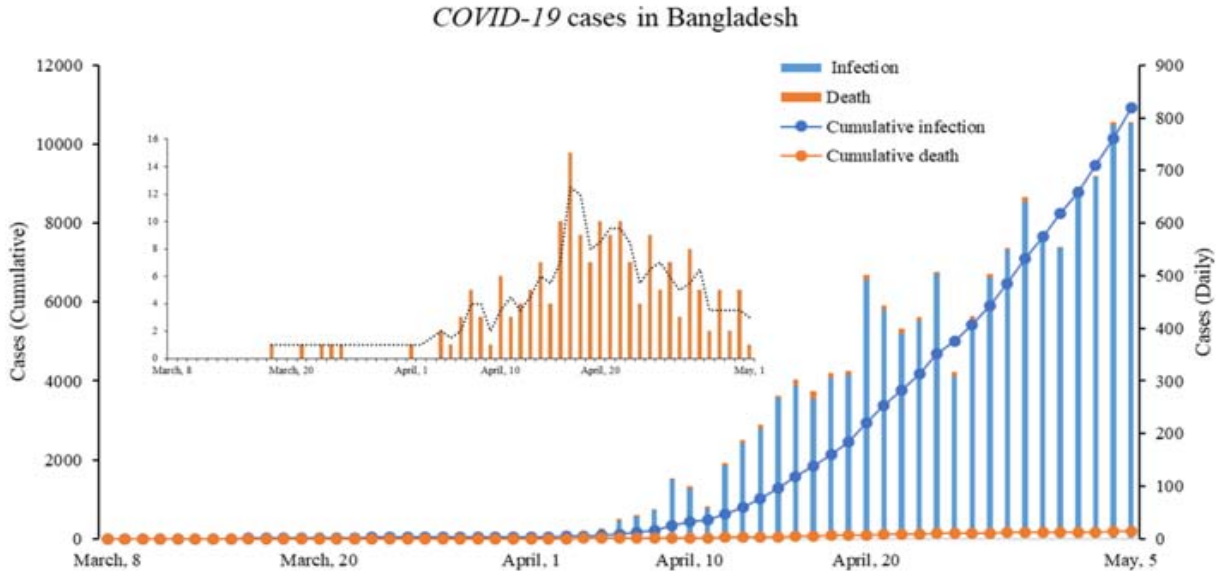

Figure 3. *COVID-19* impact on total infection and death in Bangladesh

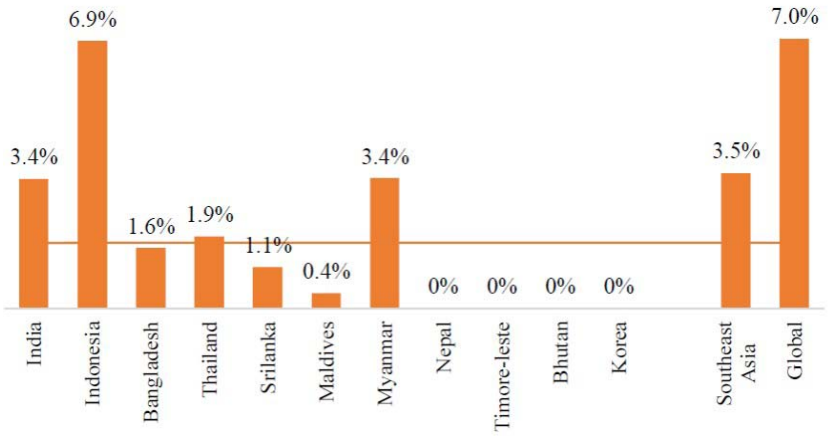

Figure 4. A comparison of the worldwide mortality rate (%) with that of Bangladesh and other regions of South-east Asia

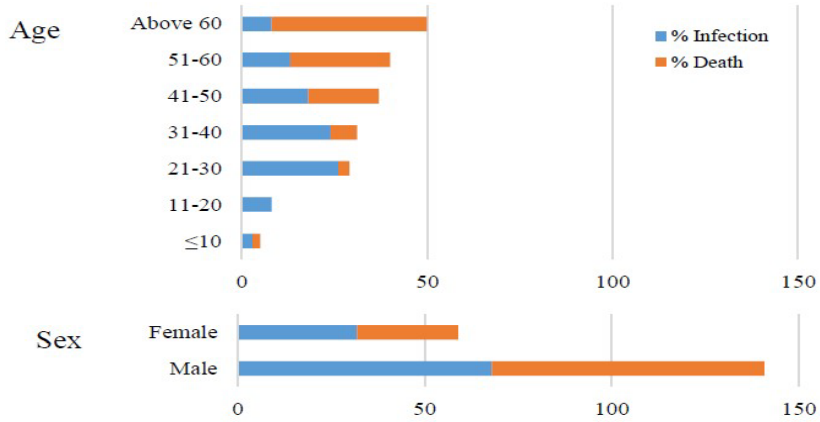

Figure 5. *COVID-19* induced infection and death in Bangladesh as varied by age and sex

3.2. The Meteorological State of Dhaka Before and During the Lockdown

Figure 6 and Figure 7 shows day-wise AQI, rainfall, and temperature before lockdown and during lockdown, respectively during the months of *COVID-19* spread out. The AQI ranged from 145 to 259, 118 to 291, and 121 to 228 with mean values of 188, 189, and 179 respectively in the years of 2018, 2019, and 2020 (Table 2).

The mean AQI increased by 0.53% in 2019, while it decreased by 4.82% in 2020 compared to 2018. On the other hand, the mean AQI decreased by 5.30% in 2020 in comparison to 2019 during the same period. Before lockdown, during the period in March, only 2 days were experienced with rain in 2018, while in 2019 and 2020, respectively 9 days and 8 days were experienced with rain. The amount of rainfall ranged from 0.7mm to a maximum of 1.7mm in 2018, from a minimum of 0.3mm to a maximum of 24.5mm in 2019 and from a lowest of 0.6mm to a highest of 15.9mm in 2020. Total rainfall was found to be 2.4mm, 38.9mm, and 43.3mm with mean values of 0.10mm, 1.56mm, and 1.73mm, respectively in 2018, 2019, and 2020. Similarly, in the successive three years, the mean daily temperature during the period ranged from 26°C to 31°C, 24°C to 34°C and 21°C to 31°C, while the average temperature was found to be 28°C, 29°C, and 28°C, respectively. Table 2 shows that the humidity varied from 25 to 61%, 28 to 67% and 29 to 69% with mean values of 43%, 44% and 44%, while the cloud content ranged from 0 to 34%, 0 to 82% and 1 to 63% with average of 8%, 18% and 24%, respectively in 2018, 2019 and 2020. During the period of lockdown in 2020, the AQI ranged from 81 to 205 with an average of 127.78, while it varied from 91 to 214 and 86 to 255 with mean values of 140.80 and 153.48, respectively during the same period in 2018 and 2019 (Table 2). From the data, it was evident that the air quality deteriorated in 2019 compared to 2018. The quality of air in 2020 improved during the lockdown period compared to the same period both in 2018 and 2019. The AQI increased by 9.00% in 2019, while it decreased by 9.57% in 2020 in comparison to 2018. When compared between the years 2019 and 2020, AQI was found to be 16.74% lower in 2020 relative to 2019. During the lockdown period in 2020, the rainfall ranged from 0.1mm to 35.9mm with a total amount of 210.40mm, whereas during the corresponding periods in 2018 and 2019, the quantity ranged from 0.1mm to 15.3mm and 0.1mm to 32.8 mm having a total quantity of 133.20mm and 265.20mm, respectively. However, the average rainfall in 2018, 2019, and 2020 were 3.25 mm, 6.47mm, and 5.13mm, respectively. The daily average temperature during the lockdown period ranged from 28°C to 33°C, 26°C to 36°C and 28°C to 36°C with mean values of 30°C, 32°C and 31.6°C, respectively in the years of 2018, 2019 and 2020. During the lockdown period in 2020 and the same period in 2018 and 2019, the humidity ranged from 19 to 70%, 44 to 75% and 31 to 75% with average contents of 50%, 59% and 53%, respectively. On the other hand, the average cloud contents were found to be 23%, 41% and 30% having the ranges of 5 to 47%, 6 to 77% and 0 to 80%, respectively in 2018, 2019 and 2020 (Table 2).

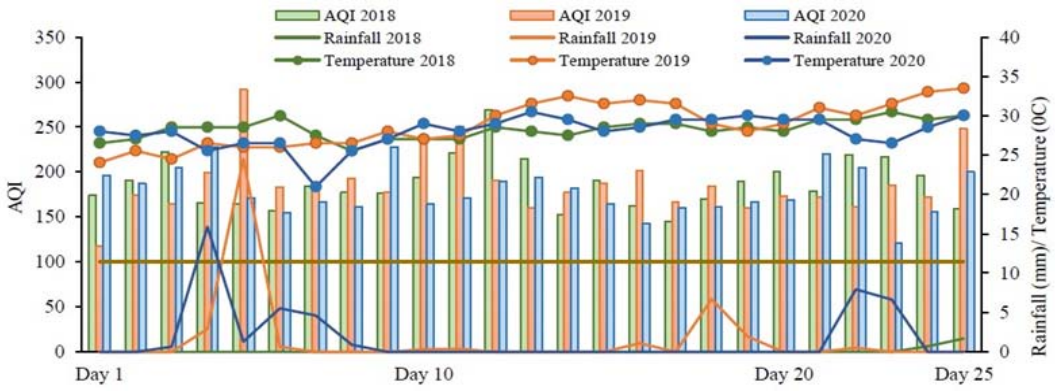

Figure 6. Day-wise AQI, temperature (°C) and rainfall (mm) before lockdown in the month of *COVID-19* spread out in 2020 and during the same periods in 2018 and 2019 (Note: The horizontal line indicates the standard limit of AQI set for Bangladesh)

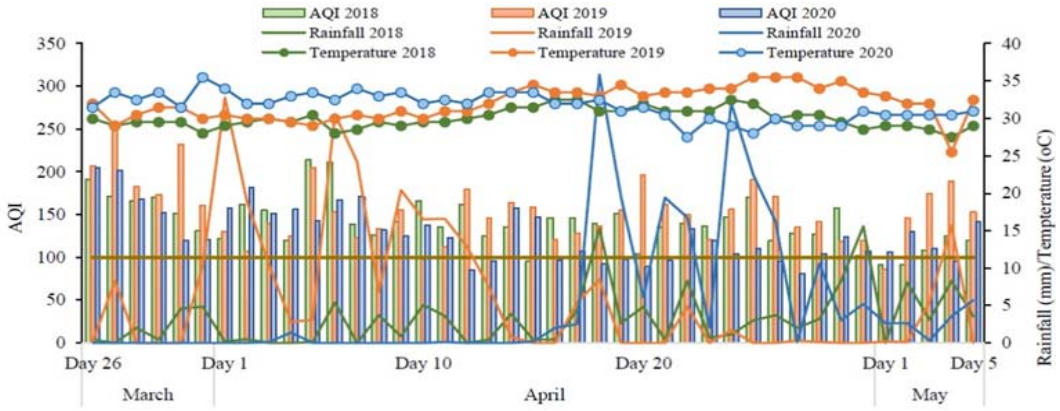

Figure 7. Day-wise AQI, temperature (°C) and rainfall (mm) during lockdown period due to *COVID-19* in 2020 and during the same periods in 2018 and 2019 (Note: The horizontal line indicates the standard limit of AQI set for Bangladesh)

Table 2. Air quality index (AQI) and different climatic parameters with statistical values

Year			Climate parameters					
			Rainfall (mm)	AQI	Temperature (°C)	Humidity (%)	Cloud (%)	Heat index
2020	01 March-25 March Before lockdown	Mean	1.73	178.56	27.92	44.28	24.24	27.64
		Minimum	0.00	121.00	21.00	29.00	1.00	21.00
		Maximum	15.90	228.00	30.50	69.00	63.00	30.60
		Median	0.00	171.00	28.00	41.00	15.00	28.13
		SD	3.75	26.38	2.02	10.88	22.08	1.87
		CV%	216.69	14.77	7.25	24.58	91.10	6.76
	26 March-05 May During lockdown	Mean	5.13	127.78	31.65	50.15	29.54	33.84
		Minimum	0.00	81.00	27.50	19.00	0.00	28.65
		Maximum	35.90	205.00	35.50	70.00	80.00	39.64
		Median	0.20	123.00	32.00	52.00	22.00	33.67
		SD	9.09	31.75	1.80	12.30	25.38	2.28
		CV%	177.09	24.85	5.68	24.52	85.93	6.75
2019	01 March-25 March	Mean	1.56	188.56	28.88	43.72	18.48	29.16
		Minimum	0.00	118.00	24.00	28.00	0.00	24.00
		Maximum	24.50	291.00	33.50	67.00	82.00	36.12
		Median	0.00	183.00	29.00	43.00	10.00	28.83
		SD	4.99	35.73	2.82	10.48	20.40	3.10
		CV%	320.99	18.95	9.76	23.98	110.37	10.62
	26 March-05 May	Mean	6.47	153.48	32.04	53.39	40.71	35.42
		Minimum	0.00	86.00	25.50	31.00	6.00	25.50
		Maximum	32.80	255.00	35.50	75.00	77.00	43.19
		Median	1.70	151.50	32.00	56.00	38.00	34.70
		SD	8.91	35.81	2.17	12.33	21.36	3.69
		CV%	137.71	23.33	6.76	23.09	52.48	10.41
2018	01 March-25 March	Mean	0.10	187.60	28.28	43.04	7.52	28.47
		Minimum	0.00	145.00	25.50	25.00	0.00	25.50
		Maximum	1.70	269.00	30.50	61.00	34.00	31.39
		Median	0.00	184.00	28.50	43.00	5.00	28.73
		SD	0.36	28.26	1.22	11.09	8.77	1.67
		CV%	377.36	15.06	4.30	25.76	116.57	5.85
	26 March-05 May	Mean	3.25	140.80	30.00	59.00	22.51	32.83
		Minimum	0.00	91.00	27.50	43.00	5.00	29.45
		Maximum	15.60	214.00	32.50	75.00	47.00	39.00
		Median	2.60	139.00	29.50	57.00	22.00	32.01
		SD	3.79	28.47	1.29	8.71	10.39	2.73
		CV%	116.60	20.22	4.30	14.77	46.13	8.32

When compared between Figure 6 and Figure 7, it was found that air pollution in terms of average AQI was higher in March compared to April and May. In contrast, the number of rainy days, as well as the total quantity of rain, were found to be higher in April and May relative to the previous month. However, the average temperature was observed higher in the month of April compared to March and May.

Table 3 presents the frequency of polluted days before and during the lockdown in 2020 and the corresponding days in 2018 and 2019. Before lockdown, in three consecutive years of 2018, 2019 and 2020, maximum days were found in the group of unhealthy representing 72%, 76%, and 72% followed by very unhealthy giving 24%, 20%, and 20%, respectively. Only 4% were found in the category of caution in 2018 and 2019, while 8% of days were found in 2020 during the month of *COVID-19* spread out before lockdown.

On the other hand, during the period of lockdown in 2020 and the same periods in 2018 and 2019, maximum days were found with caution having 59%, 46%, and 49% followed by unhealthy levels giving 29%, 42%, and 22%, respectively. During lockdown in 2020, 24% of days were found with a moderate level of pollution, while the values were only 7% and 2%, respectively in 2018 and 2019. However, air pollution with good and extremely unhealthy levels was not found in any of the days during the lockdown periods.

Table 3. Frequency of polluted days (parentheses show %) before and during lockdown in 2020 and corresponding periods in 2018 and 2019

Air quality index (AQI) range	Air pollution level	Before Lockdown			During Lockdown		
		2018	2019	2020	2018	2019	2020
0-50	Good	-	-	-	-	-	-
51-100	Moderate	-	-	-	3 (7)	1 (2)	10 (24)
101-150	Caution	1 (4)	1 (4)	2 (8)	24 (59)	19 (46)	20 (49)
151-200	Unhealthy	18 (72)	19 (76)	18 (72)	12 (29)	17 (42)	9 (22)
201-300	Very unhealthy	6 (24)	5 (20)	5 (20)	2 (5)	4 (10)	2 (5)
301-500	Extremely unhealthy	-	-	-	-	-	-

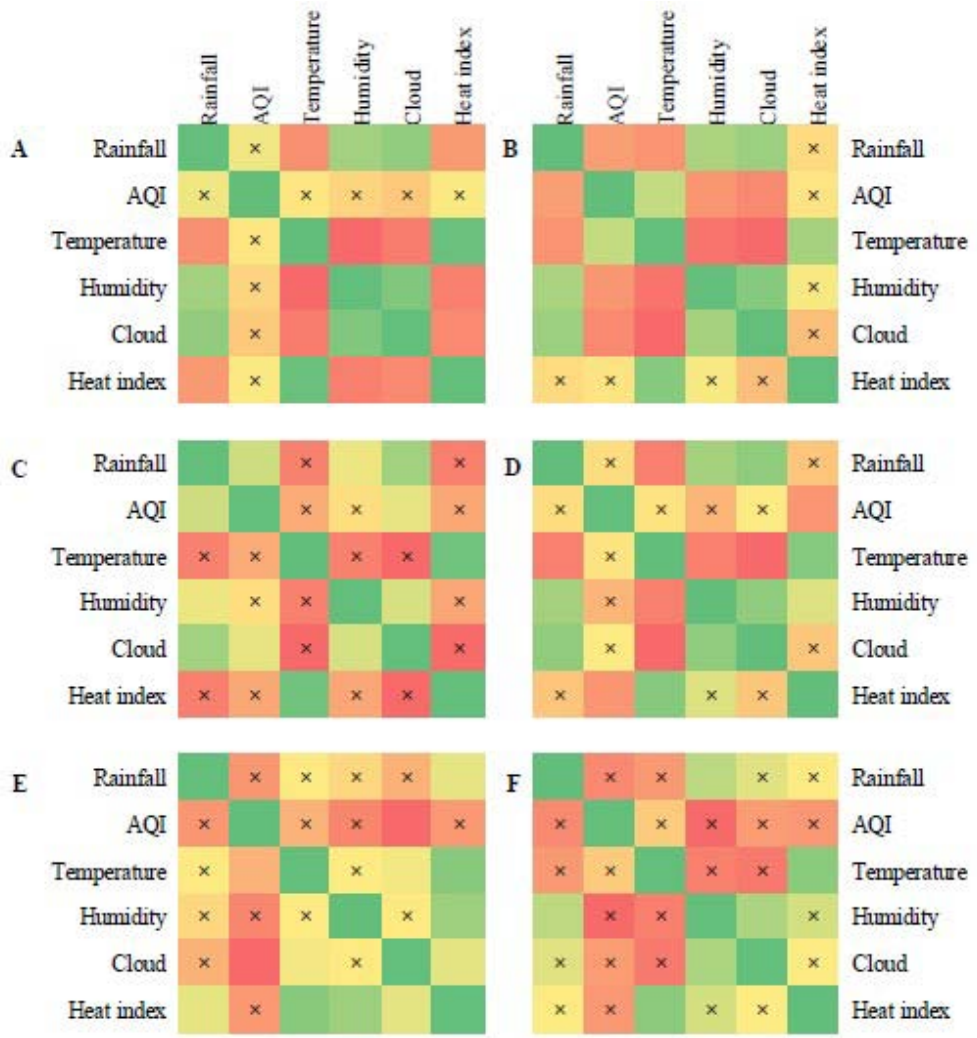

Figure 8. Correlation among the meteorological parameters between 01 March - 25 March and 26 March - 05 May for the years 2020, 2019 and 2018. Crossed boxes represent non-significant correlations. Red boxes show a negative correlation, while green boxes show positive correlations: A=01.03.2020-25.03.2020, B=26.03.2020-05.05.2020, C=01.03.2019-25.03.2019, D=26.03.2019-05.05.2019, E=01.03.2018-25.03.2018, F=26.03.2018-05.05.2018

3.3. Correlation among Meteorological Parameters

A correlation was made among AQI, rainfall, and temperature in the respective years. Correlation between rainfall and temperature was negative for all the months of the observation period (Figure 8). A negative correlation was found between AQI and rainfall data. From the negative correlation between AQI and rainfall (-0.42, $P<0.05$), it can be said that the AQI in 2020 would be lower than the existing value if the lockdown period was experienced with more rainfall as happened in 2019. The correlation coefficient between different parameters are shown in Figure 8.

3.4. Relation of Air pollution with *COVID-19* Infection

Bangladesh's capital, Dhaka was ranked as one of the most heavily polluted cities in the world. Annual mean air particulate matter and mortality rate in the major cities of Bangladesh: Barishal, Chattogram, Dhaka, Khulna, Rajshahi and Sylhet, are shown in Figure 9. The number of death for *COVID-19* was the highest in Dhaka, which was 40 times higher than the second most polluted city, Chattogram.

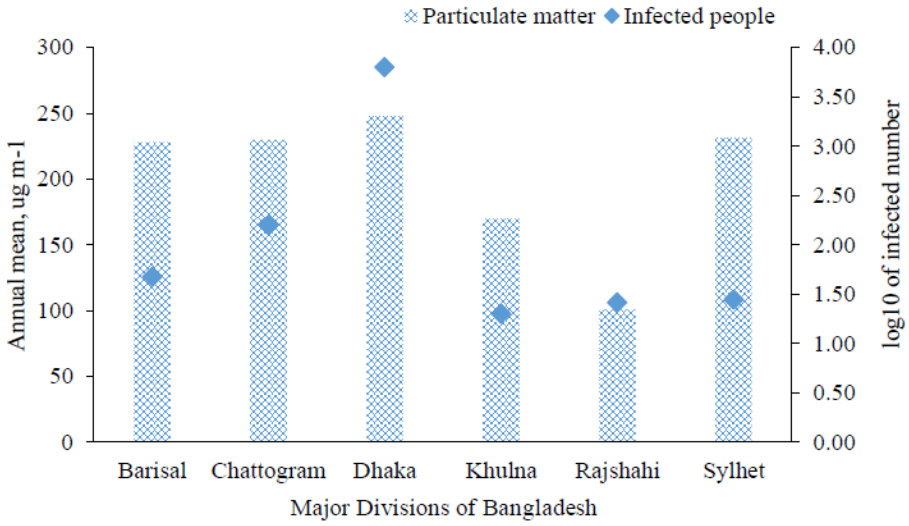

Figure 9. Air pollution levels and the number of infections in different divisions of Bangladesh

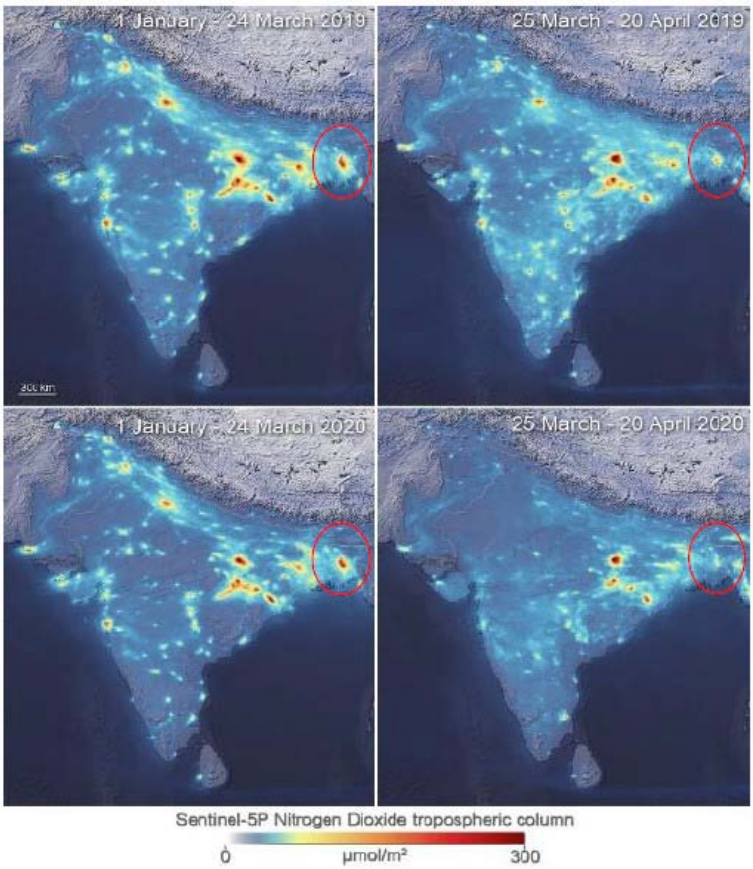

Figure 10. Nitrogen dioxide (NO_2) concentrations over India and Bangladesh [21]

The Government of Bangladesh has recently imposed lockdowns in order to cease the outspread of *COVID-19*. This has resulted in a cleaner air quality all over the country. Satellite images from the Copernicus Sentinel-5P satellite, the European Union Copernicus programme, reported that air pollution level in some cities of India dropped by 40-50% for the extensive lockdown. Figure 10 also clearly showing a similar situation in Bangladesh. The images show NO_2 concentrations over Bangladesh from 1st January to 24th March 2020 and 25th March to 20th April 2020 and in the corresponding time-frame of the previous year. A significant reduction in air pollution was also detected over major cities of Bangladesh (marked by oval shape).

4. Discussion

4.1. *COVID-19* Induced Health Effects

The impacts of *COVID-19* on human health, global economy, education, global food security, and the environment have already gained lots of attention to the global community. The infected cases and death tolls due to *COVID-19* is increasing at a very rapid rate globally.

The spread of this virus worldwide poses serious threats to human health. As of 10th May 2020, a total of 4,633 persons were died out of 82,901 infected cases in China [22] where this virus was first identified. Though the number of deaths in China is stable, the number of deaths and infections are sharply rising outside China. Now, there are more cases every day in Europe, America, Asia, Africa and Oceania. The increasing trend of infection due to *COVID-19* in Bangladesh may be either due to the rapid spread of the virus among the people or an increased number of test countrywide with time. The number of sample collection and the *COVID-19* testing capability in Bangladesh increased over time. However, the infection and death rate varies depending on location, age, sex, and past health complications. At the end of March, the death rate due to *COVID-19* in Italy was more than 11% whereas, in Germany, mortality was about 1%. The fatality rate is lower in countries having a facility of extensive and systematic testing in comparison to countries where testing is not widespread [23]. As of 16th March 2020, in the USA, the highest death rate of 47.7% was found in peoples aged above 75 years followed by 24.6% in peoples with the age range of 65 to 74 years [24]. According to a report published by WHO, in Bangladesh, more than 60% of the confirmed cases were between 21 and 50 years old, while the age group of lower than 20 years represented only around 10% [25]. It was also observed that the mortality rate was higher among patients who had pre-existing health conditions such as cardiovascular diseases, hypertension, diabetes chronic respiratory disease, and cancer [2]. The higher mortality rate of aged people may be associated with an immunity system that deteriorates with age.

4.2. Air Quality Before and During the Lockdown

The AQI data before and during lockdown due to the *COVID-19* outbreak of the 2020 and two previous years was compared with different air quality ranks as set for Bangladesh. The average AQI before the lockdown was found to be unhealthy for everyone in the current year and also in the previous two years during the same period (Table 2). However, interesting results were found when the air quality during the lockdown period of the present year due to *COVID-19* was compared with the same periods of 2018 and 2019. During the period of more than one-month lockdown due to *COVID-19* resulted in better air quality in terms of mean AQI that was merely unhealthy for a sensitive group of people and general people was not likely to be affected. On the other hand, the air pollution level in 2019 during the same lockdown period of 2020 was found in the category of unhealthy not only for sensitive groups but also for everyone. The pollution level increased in 2019 compared to 2018 and again decreased in 2020 relative to both 2018 and 2019.

The decline in air pollution in Dhaka city in the present study during the *COVID-19* outbreak resulted from the lockdown of most industrial and commercial activities, the shutdown of the government and private offices, and restricted movement of public vehicles. Similar results have been found in China, where air pollution declined tremendously due to the official decision to quarantine of major cities and lockdown of most industrial and commercial activities to stop the outbreak of the *COVID-19*. The shutdown of coal-fired power plants and other industrial activities during lockdown resulted in upto 25-30% reduction in air pollution [4,26]. In another study, the average NO_2 level in the troposphere was found to be declined by 36% during the period of *COVID-19* spread out compared to the same period in 2019 which might be due to reduction in fossil fuel use and limitation over vehicle driving to control the outbreak of the virus [27].

The meteorological parameters such as humidity, wind speed, pressure, temperature, and rainfall have influences on distribution, deposition, concentration, and dilution of pollutants in the atmosphere [28,29]. The pollutants, both gaseous and PM, in the atmosphere, may be washed out by the process of wet deposition or dry deposition. The rainfall has been found to decrease the levels of gaseous pollutants and PM from the atmosphere by several studies [30,31,32]. A linear negative relationship was found between the intensity and duration of the rainfall and the removal of PM from the atmosphere and the effectiveness of the removal of PM was the same at the same intensity and duration of rainfall at different locations [31]. Rain plays an important role in the natural washout of atmospheric pollutants. The pollutants in the atmosphere are removed either by absorption or impaction processes. However, the removal of pollutants and their equilibrium in the atmosphere is directly proportional to the rates of emission of pollutants and the intensity of raindrops falling on the ground. The removal of gaseous pollutants from the atmosphere is greater when these pollutants are converted to PM at a rapid rate and the rainfall intensity is high [32].

4.3. Loss due to Low Air Quality

Though the quality of air in Dhaka city improved during the lockdown, the mean AQI value was not within the standard limit (AQI≤100) set for Bangladesh. The

movement of transports carrying goods, cargo and emergency vehicles, partial commercial, and industrial activities resulted in emissions of pollutants in the atmosphere and ultimately resulted in higher AQI values. PM as air pollutant has toxic effects on the cardiovascular and respiratory systems of the human body; besides, it is a potent oxidant that has direct effects on lipids and proteins and intracellular oxidant pathways [33]. An Epidemiologic research has found a significant association of an increased risk of all causes of mortality, cardiopulmonary mortality, and lung cancer mortality with increased exposure to air pollution [34]. It was estimated that about 29% of lung cancer deaths, 24% of stroke deaths, 25% of heart disease deaths, and 43% of other lung diseases are caused by ambient air pollution [35]. Children are more susceptible to air pollution. Air pollution is responsible for asthma of up to 14% of children worldwide within the age group of 5-18 years. About 0.54 million children younger than 5 years die every year from air pollution-induced respiratory problems. However, air pollution is equally harmful to the cognitive development of both children and adults [12]. Worldwide, about 7 million people die every year because of air pollution. In urban areas, more than 80% of people are exposed to air pollution higher than the permissible limit, where low- and middle-income countries are more susceptible to both indoor and outdoor air pollutions [35]. About 4.3 million people die from household air pollution and 3.7 million from ambient air pollution, most of whom (3.3 and 2.6 million, respectively) live in Asia [36]. WHO reported that 4 million people, mostly in Africa and Asia, die each year from household air pollution because of using unpurified fuels and faulty technologies at home for cooking, heating, and lighting [12]. It was estimated that in 2016, air pollution was responsible for more than 6 million deaths worldwide [4,11]. However, Lelieveld et al. [37] showed that an excess mortality rate of 2.96 to 4.21 million per year can be avoided from outdoor air pollution worldwide and also found that about 65% of the excess mortality rate was attributed by emissions from combustion of fossil fuels. Similar health effects of air pollution in Bangladesh have been found in previous years. Vehicles and industries are the primary sources of emissions of PM leading to urban air pollution in Bangladesh. It was found that in Bangladesh, indoor and outdoor air pollution led to 12.3 million deaths in 2017 [38]. In 2018, a total of 9.6 million children died of diseases caused by air pollution in Bangladesh, and more than 4 million patients suffered from respiratory diseases such as breathing problems or asthma because of heavy air pollution [39]. PM is a pollutant of special concern. Plethora of studies are available which showed a direct relationship between exposure to air pollutants and negative health impacts [40,41,42].

The average value for 'satisfactory' air is 50 $\mu g/m^3$ PM. PM can penetrate tissues and organs, which can deteriorate physical functioning and can even be fatal at a very high pollution level. General people of Bangladesh have low physical strength than average in the world due to a lack of proper nutrition. Their capacity to fight against diseases is low. When highly skilled workers cannot work because of sickness or death due to the air pollution, industries face losses, which can cause economic suffering pessimistically. Treatment costs incur both families and public agencies. This was equivalent to 0.6% and 0.1% of Bangladesh's and Dhaka's GDP in 2015, respectively. WHO estimated the economic impact of extreme air pollution on workers and the output was US$6.52 billion in urban Bangladesh and US$1.44 billion in Dhaka alone, which were equivalent to 3.4% and 0.7% of the GDP in 2015, respectively [43].

In severe cases of *COVID-19*, the respiratory tract of the human body is infected. So, a person who has a weak respiratory system due to long exposure to polluted air, can be very vulnerable to the disease. Even an insignificant increase in particulate matter in air pollution can make the *COVID-19* deadlier, according to new research [44]. The report looked at the air pollution and *COVID-19* deaths in 3,000 United States provinces. The study deduces that the death rate of *COVID-19* can increase by 15% if PM increases in air 1 $\mu g/m^3$. The increase of transmission dynamics of *COVID-19* in Dhaka has a high interrelation with air pollution of metropolitan cities which has a harmful level of PM. Cities having a high level of PM (exceeding the limits set for PM) in Bangladesh had a very high average number of infected individual and death rates whereas cities having less than the toxic limit of air pollution had a lower average number of infected people (Figure 9). Coccia [45] revealed that the mechanisms of air pollution-to-human transmission play a critical role in dynamics of *COVID-19* diffusion in polluted environment.

In a study, Burke [46] calculated that the *COVID-19* induced economic disruption reduced air pollution in China that saved twenty times more lives than have currently been lost directly due to infection with the virus. However, the question is that would the changes in air pollution trends or death rates due to the reduction in air pollution go beyond the number of deaths caused by *COVID-19* and also could compensate for the economic loss of Bangladesh due to *COVID-19* induced lockdown? It is still not possible to predict the number of infected persons in preceding days as well as how many deaths will occur as a result of this virus. The reduction in air pollution due to *COVID-19* might have short term benefits to human health but the consequences of the outbreak need to be evaluated in the dimension of financial disruption of the country.

4.4. Effects of Lockdown on the Economy of Bangladesh

COVID-19, one of the most devastating pandemics of the century, affects all spheres of life from the environment to the economy, leaving the world in a state of stalemate and sheer stagnation. The outbreak has disrupted social, economic, political, religious, and financial structures of the whole world. Figure 11 demonstrates the vivid picture of different sectors of Bangladesh's economy that would be affected by the *COVID-19* induced containment.

Needless to say that South Asia finds itself in a tempest of *COVID-19* and Bangladesh is not an exception. Demand for garments has collapsed, and inflows of remittances are being disrupted significantly, tourism has dried up, the interconnectedness of modern economies

implicate supply chains, consumer demands are at an unprecedented low, all mega projects of the government are at an unforeseen standstill and utter deterioration of investor sentiments also add to its culmination. On top of, deterioration of the international environment, the lockdown in Bangladesh has frozen large parts of the domestic economy. The impacts of *COVID-19* on external sector performance as well as over economy of Bangladesh is shown in Figure 12.

The apprehension is that pandemic affects the entire economy as well as all the sub-sectors of the same. One of the major problems that affect the entire activities of an economy ultimately hampers all aspects of national and human life.

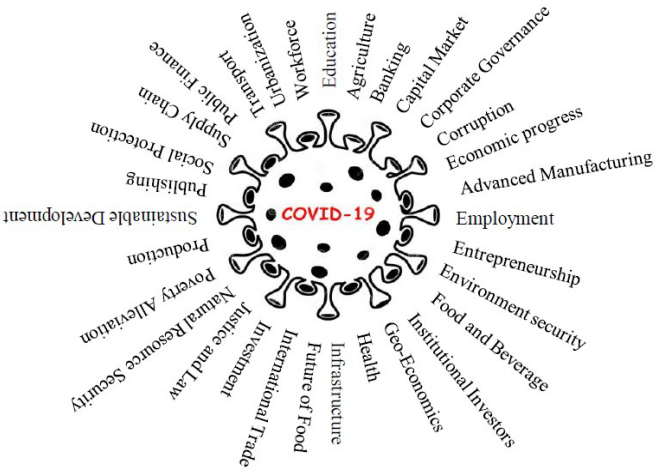

Figure 11. Different sectors of Bangladesh which are challenged by the unprecedented crisis of *COVID-19* [47]

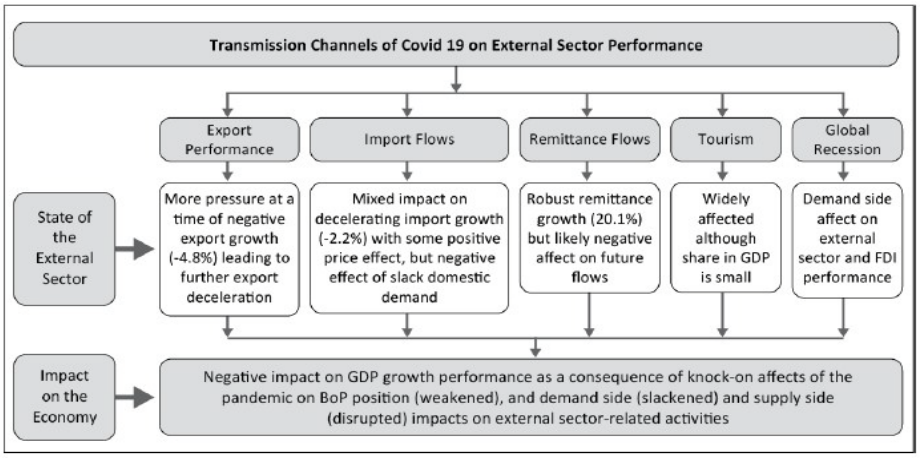

Figure 12. Impacts of *COVID-19* on external sector performance and economy of Bangladesh [48]

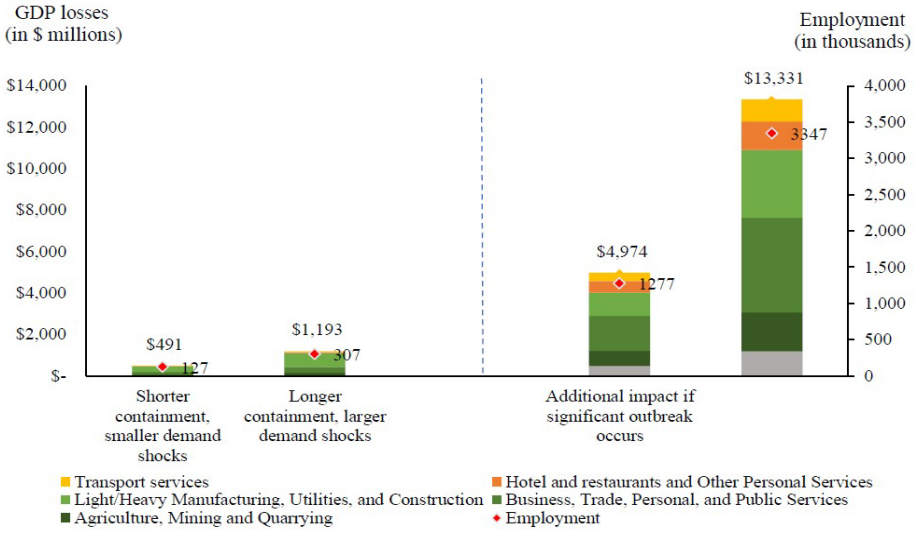

Figure 13. *COVID-19* Economic Impact Assessment Template for Bangladesh. In this figure, "$" refers to the United States dollars [49]

The recent mayhem in the world economy due to *COVID-19* induced abrupt halt of commercial activity began to manifest the patterns and tendencies of the economy in near future and so long as human contact remains precariously dangerous, businesses cannot responsibly return to normal. This will, in turn, reconfigure the data on consumer-led economic growth, investment, unemployment and poverty. Figure 13 shows the forecasting of *COVID-19* induced short term and long-term effects on different sectors of Bangladesh. Asian Development Bank (ADB) calculated the potential economy and sector-specific impact of the *COVID-19* outbreak. There will be large downward revisions of the forecast for the years 2020 and 2021. Growth in domestic consumption in outbreak-affected economies will be declined by 5% for longer and 2% for shorter whereas growth in domestic investment in outbreak-affected economies will be declined by 6.25% and 2% for longer and shorter contaminant respectively. Growth is forecasted to decelerate to 3.0% in the year 2020 with declining garment exports, lower private investment growth, and border disruptions caused by *COVID-19*. In the absence of mitigation measures, poverty is expected to increase significantly due to *COVID-19*. From the variation of the forecasted GDP of the country, it means that significant parts of the population would lose income during these two years.

Global remittances are projected to decline sharply by about 20% in 2020 owing to the economic catastrophe induced by the *COVID-19* pandemic and massive lockdown in almost all the countries of the world [16]. Bangladesh is a remittance-reliant economy where remittances are vital sources of external financing. Figure 14 shows the fall in remittance flown in different regions due to *COVID-19*. From the figure, it is evident that the highest fall in remittance is expected in Europe and Central Asia which accounted for 27.5% followed by Sub-Saharan Africa where the remittance fall is expected to be 23.1%. On the other hand, the lowest fall (13%) in remittance is expected to be in East Asia and the pacific. However, in South Asia, it is expected that the remittance flows would fall by 22.1%. Therefore, the remittance flows in Bangladesh are projected to decline by about 22% due to the economic crisis induced by the *COVID-19* pandemic and lockdown.

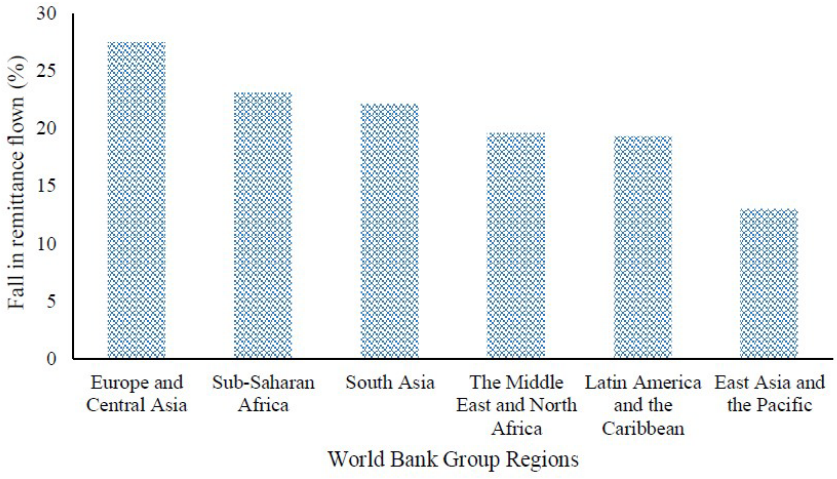

Figure 14. Impact of *COVID-19* on remittance flows across all World Bank Group regions [16]

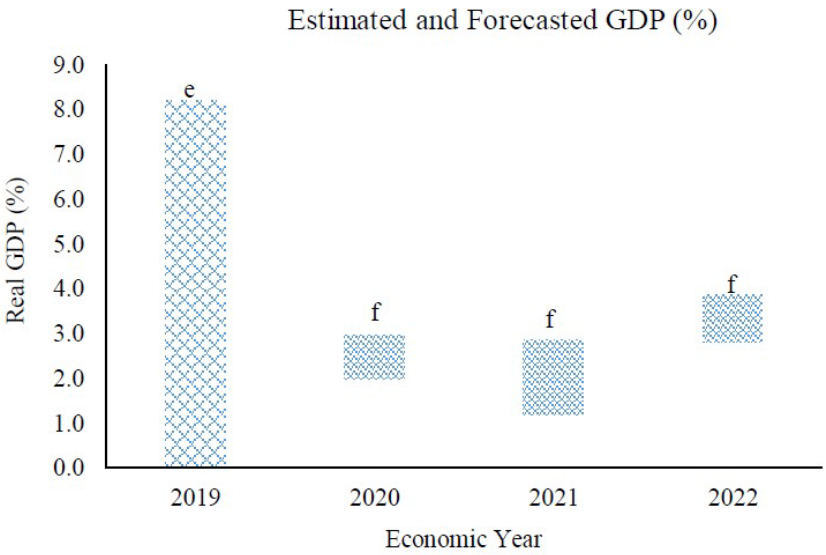

Figure 15. Estimated and forecasted GDP (%) at market prices of Bangladesh [52] (Notes**:** 2020, 2021, and 2022 numbers represent the lower and upper bound of the forecast range. **e**: Estimate **f**: Forecast)

Since the outbreak of *COVID-19*, more than half a million people, including migrant workers have returned to Bangladesh in March 2020 mostly from the Gulf and Southeast Asian nations, the USA, UK, and Italy, where they were employed. It was reported that the remittance inflows in March of the current year decreased by 12% compared to the corresponding period last year [50]. These cause an economic recession and ultimately may provoke the poverty of vulnerable peoples resulting in their inability to meet basic needs such as food, health, education, and so on. The transport workers, retail traders, vendors, hospitality workers are the most vulnerable groups who are not under social safety and therefore, the worst sufferer. The rate of extreme poverty could be doubled (21.8 %) in the current fiscal year due to *COVID-19* which was 12.8% in the last fiscal year. While the lower-income poverty rate could jump to 58.3% in the current fiscal year, which was 49.3% in the last fiscal, the upper-middle-income poverty rate also may increase to 91.8% in this fiscal from 82.8% in the last fiscal year [51].

In the face of gross uncertainty, Figure 15 shows a forecast, estimating real GDP growth, which would plunge to a range between 2% and 3% in 2020. The *COVID-19* pandemic is set to bring down Bangladesh's GDP growth from a high-flying 8.2% last year to just 2% this year ending in June 30. Such a decline in GDP growth leads Bangladesh to a growth rate dipping below 3% that would be the worst achievement in the last 40 years. This decreasing trend of the forecasts will remain till 2021, with growth projected to linger between 1.2 and 2.9%, down from the previous 3.0 % estimate and afterward, a positive trend in 2022 with a growth rate between 2.8 and 3.9%.

Bangladesh is facing double trouble of unemployment by the decline in local and global demand for manufactured products like a readymade garment as well as the decline in global demand for labors worsening the situation. The *COVID-19* pandemic appears to own a devastating impact on global garment offer chains, and therefore, the state of affairs can get so much worse. Since the outbreak of *COVID-19*, 45.8% of Bangladeshi suppliers report that most of their nearly completed or entirely completed orders were canceled by their buyers. About one million garment employees in Bangladesh had been permanently or temporarily sacked due to order cancellations and therefore the failure of patrons to compensate for these cancellations. It was reported that 98.1% of patrons refused to contribute to the price of paying the partial wages to furloughed employees and 72.4% of furloughed employees were sent home without paying their salaries [53]. The pandemic could lead to high inflation along with high unemployment.

There is no doubt that the economy of Bangladesh has been significantly impacted by the *COVID-19* pandemic. However, the consequences of the *COVID-19* on economic disruption depend on the duration of the lockdown. The employment in all countries of the world would drastically fall if the lockdown lasts for two months and the situation would be worsening if the lockdown is prolonged for four months. World Bank warns that long term lockdown and economic disruption resulting from the *COVID-19* crisis may cause widespread food shortages for low-income people, especially informal workers in the hospitality, retail trade, and transport sectors [52].

5. Conclusion

The spread of the *COVID-19* has already caused the infections and deaths of millions of people worldwide. Though it is beyond the doubt that the *COVID-19* has severe health hazards, the effects of this novel virus in dimensions of economic disruption cannot be overlooked. The Dhaka city has ranked as the most polluted city in the world for several years, making the people vulnerable to health hazard. The restricted vehicular movements, as well as commercial and industrial activities, were found to reduce air pollution of Dhaka city to a certain extent due to reduced emission of pollutants in the atmosphere which has positive impacts on residents' health. However, the outbreak of *COVID-19* has already posed a long term economic challenges to the global community. The economy of Bangladesh is as important as health and environment. The economic loss due to the shutdown of the commercial and industrial activities of a low-income country like Bangladesh is immense and also a great threat to poverty alleviation. Thus, it is important to run the economic growth taking into consideration the severity of *COVID-19* as well as realizing the importance of our environment. The government of Bangladesh should take a comprehensive strategy to run all commercial and industrial activities and at the same time to minimize community transmission of *COVID-19* and also to reduce environmental pollution through sustainable activities. Moreover, the government should take immediate strategies to overcome present financial loss and also take long term policies to strengthen the economy of Bangladesh. This manuscript is meant to guide policymakers in determining the impact of the measure taken for the unprecedented crisis of *COVID-19*, so the benefits and costs of prevention and early response can be properly evaluated.

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