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Air quality index (AQI) changes and spatial variation in Bangladesh from 2014 to 2019

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ABSTRACT

Introduction: The quality of air is becoming progressively worsen day to day. The increasing concentration of air pollution and its associated health effects are rapidly rising in Bangladesh and have drawn attention in recent years. The purpose of the research is to look into the increasing levels of air pollution in Bangladesh, specifically the proportion of Air Quality Index (AQI) in four seasons and six districts, monthly mean AQI, the correlation between $PM_{2.5}$ and AQI between 2014 and 2019.
Materials and methods: The AQI data from six monitoring stations have been collected for research purposes from Continuous Air Monitoring Stations (CAMS). MS Excel 2020 and IBM SPSS V27 were used for the analysis.
Results: This study reveals that air quality in six districts of Bangladesh has been declining from 2014 to 2019, with winter and monsoon seasons being the most polluted. Dhaka and Narayanganj were found to have the unhealthiest air quality. There is a strong relationship between Paerticulate Matters ($PM_{2.5}$) and AQI, with AQI increasing with the amount of $PM_{2.5}$ in all cities. In January, February, March, November, and December, the monthly mean AQI was higher, but in May, June, and July, the mean was lower. The F-values were significant based on seasons and stations. Overall, the study highlights the increasing air pollution and associated health effects in Bangladesh.
Conclusion: Air pollution in Bangladesh is a significant issue due to industrialization, urbanization, transportation, and fuel use, resulting in consistently high AQI levels throughout the year except during rainy months.

Introduction

The term "Air Quality Index (AQI)" refers to a report on quality of air and its implications on health of human. Typically, this is a daily quality index. It indicates if the air is clean or polluted, what possible health effects

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are involved, and what safety measures should be taken in that situation [1, 2]. A serious environmental issue arises from air pollution because of its severe effects on human health [3]. For many decades, air pollutants have increased continuously in the different cities in Bangladesh. Globally the population influx in urban areas has been more in recent decades, particularly in those country's economic condition lies between low and middle income [4]. Air pollution occurs in cities where construction work is active, including Dhaka, Barisal, Chattogram, and Gazipur; Narayanganj; and Sylhet. [5-7]. Air pollution is caused by expanding cities, increased vehicle traffic, accelerating economic growth, and more consumption of energy [8-11]. Brick kilns, motor vehicles, burning of fossil fuel and biomass, dust from soil, sea salt, etc., all generate particulate matter [11-13]. Sources of particulate matter include industrial processes, transportation, construction and demolition activities, and agricultural operations [9]. Industrialization and urbanization are the primary reasons behind air pollution, in the current decades, which has become a troublesome factor [11, 14]. In comparison to rural areas, the concentration of Particulate Matter (PM) and other pollutants are more in urban areas since these are the source of major emission. Within the last decade the population growth of different cities has been very high, and so has the number of vehicles, which causes a rise in the amounts of pollutants in the air. The burning of fossil fuel and biomass also generates fine particles, $PM_{2.5}$. The emission of particulate matter depends on the design of the vehicle's engine that is whether the engine is under-powered and poorly maintained and if there is fuel loss because of over-fueling [15-17]. Additionally, the higher concentration of particulate matter was identified in that areas where motorized vehicle movement was higher like Dhaka City and less in that areas where non-motorized vehicle movement was found or no vehicle [9]. Among others, the brick manufacturing industries are significantly helping in, not only polluting the air but also, deteriorating the surrounding environment due to the usage of traditional kilns which have become outdated and use poor-quality fuels [11, 16, 17]. Study discovered a significant correlation between brick kiln surrounding Dhaka and $PM_{2.5}$ level [11]. Particulate matter having an aerodynamic diameter equal of less than 2.5 µm is known as $PM_{2.5}$; it has consisted of a lifetime that ranges from days to weeks in the atmosphere, enabling it to travel thousands of kilometers, and causing it to pollute transboundary regions [18]. Studies have shown the outflow of PM towards the north-eastern direction (where Bangladesh is situated) from the South-Asian countries during the winter [7]. The washout effect of rainfall and inversion phenomena influences the concentration of particulate matter as an air pollutant [14]. Particularly in dry season (between November and April), Dhaka city and adjacent areas have extremely high levels of Particulate Matter (PM) in the atmosphere. During the winter (between November and January), this concentration exceeds annual standard guideline value provided by World Health Organization (WHO). [7, 10, 11-14]. During the winter season, the fine particulate matter ration is relatively higher in Dhaka city; since, at this time there is more burning (of wood, paper, scraps, etc.) to generates heat and also due to more vehicular emissions [14]. Therefore, air pollution influences diseases that are rapidly increasing for the past few years and along with other environmental pollution. Particulate particles undoubtedly pose a serious hazard to human health, according to several scientific research. It is also responsible for reducing the average human life expectancy and affecting human health as well. As a result, around 2.5 million people die annually due to both indoor and ambient air pollution [19- 22]. Although it has a great impact; however, people are still not aware regard on it, Health precaution generally related to the Air Quality Index (AQI). Particulate Matters (PM_{10} and $PM_{2.5}$), Ozone (O_3), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO) and Sulphur Dioxide (SO_2) are the 5 criterion pollutants on which Bangladesh's AQI is based. The Department of the Environment (DoE) has also declared a National Ambient Air Quality Standards (NAAQS) for certain pollutants. These requirements seek to safeguard against adversely impact on human health [23]. The Bangladesh AQI standard is listed as follows in Table 1.

Materials and methods

Study area

The Clean Air and Sustainable Environment (CASE) Project implemented by Department of Environment (DoE) installed nine Continuous Air Monitoring Stations (CAMS) in six districts of Bangladesh. Three of these CAMS were located in Dhaka, two in Chittagong, and one in each of Barishal, Gazipur, Narayanganj, and Sylhet. The collected data for this study were collected from these CAMS.

Table 1. Bangladeshi Air Quality Index (AQI) with color indication.

S/N	Air quality index (AQI) range	Color	Category
1.	0-50	Green	Good
2.	51-100	Yellow Green	Moderate
3.	101-150	Yellow	Caution
4.	151-200	Orange	Unhealthy
5.	201-300	Red	Very Unhealthy
6.	301-500	Purple	Extremely Unhealthy

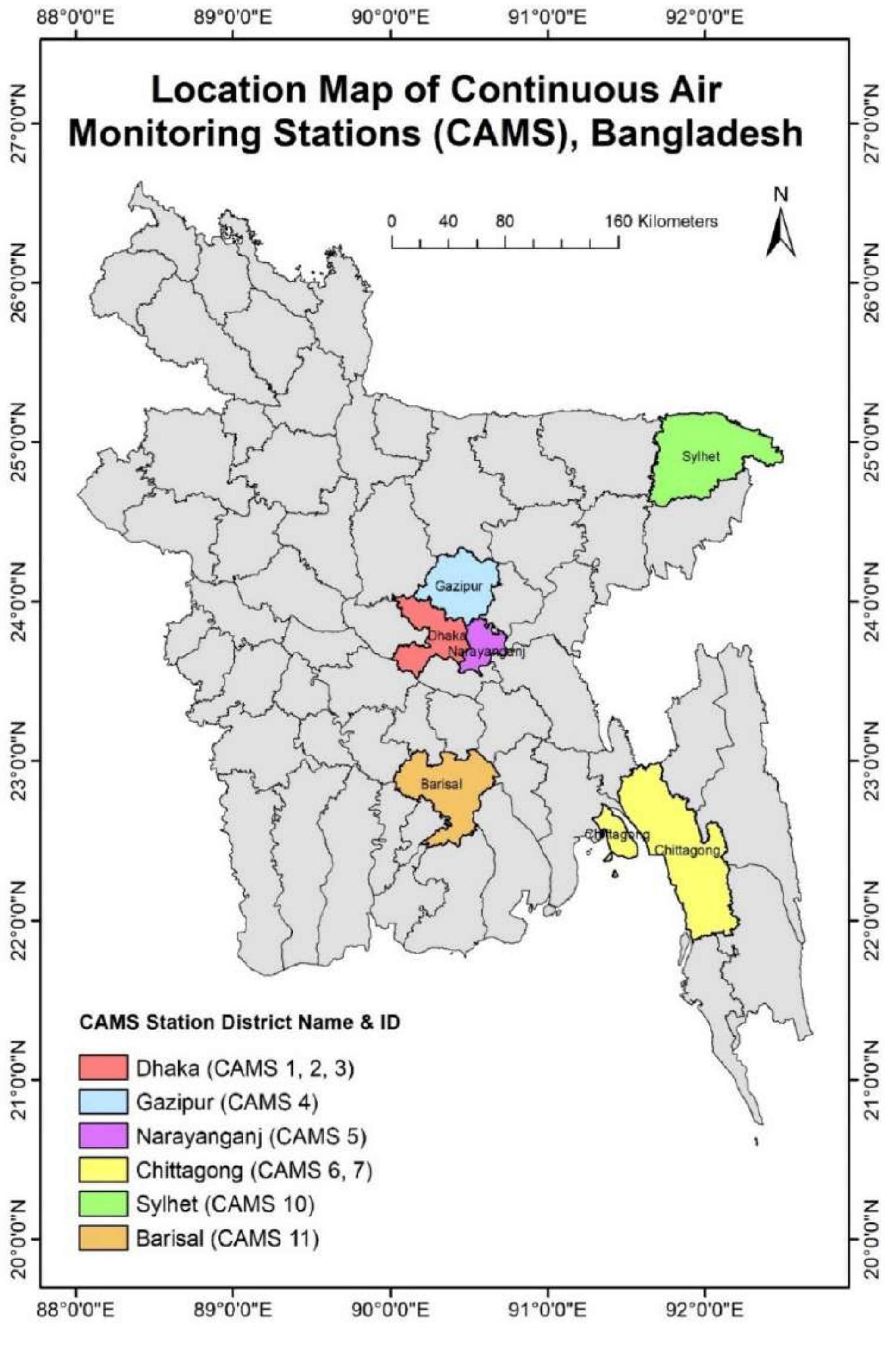

Fig. 1. A map showing the locations of the CAMS in Bangladesh

Table 2 provides a short overview of the monitoring stations as well as the list of measured parameters that were collected at each location.

Table 2. A brief description of CAMS

City	ID	Location	Lat./Lon.
Dhaka	CAMS-1	Sangshad Bhaban	23°45'36.0"N 90°23'24.0"E
	CAMS-2	Farmgate	23°45'36.0"N 90°22'12.0"E
	CAMS-3	Darus-Salam	23°46'48.0"N 90°21'36.0"E
Gazipur	CAMS-4	Gazipur	23°59'24.0"N 90°25'12.0"E
Narayangonj	CAMS-5	Narayangonj	23°37'48.0"N 90°30'36.0"E
Chittagong	CAMS-6	TV station, Khulshi	22°21'36.0"N 91°48'00.0"E
	CAMS-7	Agrabad	22°19'12.0"N 91°48'36.0"E
Sylhet	CAMS-10	Red Crescent Campus	24°53'24.0"N 91°52'12.0"E
Barisal	CAMS-11	DFO office campus	22°42'36.0"N 90°21'36.0"E

Data retrieving and analysis

Data from 2014 to 2019 were stored and published on the official website of the CASE project: http://case.doe.gov.bd. All data were retrieved for the website and re-input in a MS Excel table. IBM SPSS V27 and MS Excel 2020 were used for analysis. Multiple graphs, tables, and plot diagrams were generated to understate the data nature. To identify the seasonal change of the AQI values. Winter season comprised the months of December, January, and February; summer season included the months of March, April, and May; monsoon season included the months of June, July, August, and September; and the months of October and November were considered the post-monsoon season. The findings have been tested with statistical and Duncan's multiple range tests using a ANOVA (One-Way Analysis of Variance) based on several seasons and stations.

Results and discussion

Proportional analysis

Figs. 2 to 7 show six AQI classes proportions throughout various seasons for Barisal, Chattogram, Dhaka, Gazipur, Narayangonj, and Sylhet in 2014 to 2019. There were 6 AQI categories, Class A: Good, Class B: Moderate, Class C: Caution, Class D: Unhealthy, Class E: Very Unhealthy, and Class F: Extremely Unhealthy denoted by the colors green, yellow, orange, red, and purple, respectively.

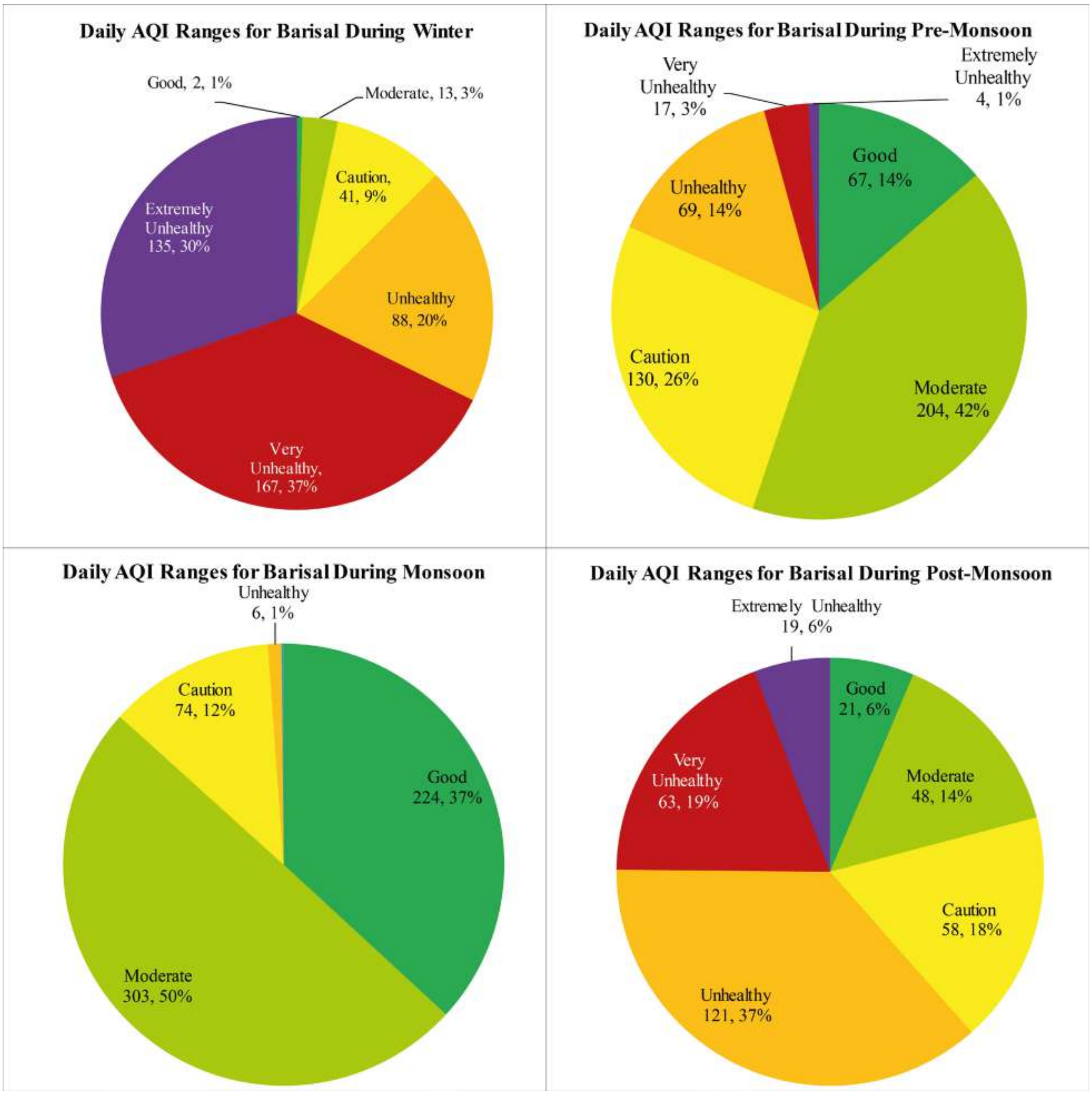

Fig. 2. The ranges of daily AQI for Barisal

Fig. 2 illustrates the ranges of daily AQI for Barisal. In Winter, the percentages of AQI classes A, B, C, D, E, and F were, respectively, 1%, 3%, 12%, 32%, 35%, and 17%. Pre-Monsoon AQI class A, B, C, D, E, and F percentages were 7%, 35%, 25%, 23%, 7%, and 3%, respectively. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 62%, 30%, 6%, 1%, 1%, and 0%, respectively. The proportions of AQI classes A, B, C, D, E, and F during Post-Monsoon were 14%, 23%, 26%, 25%, 9%, and 3%, respectively.

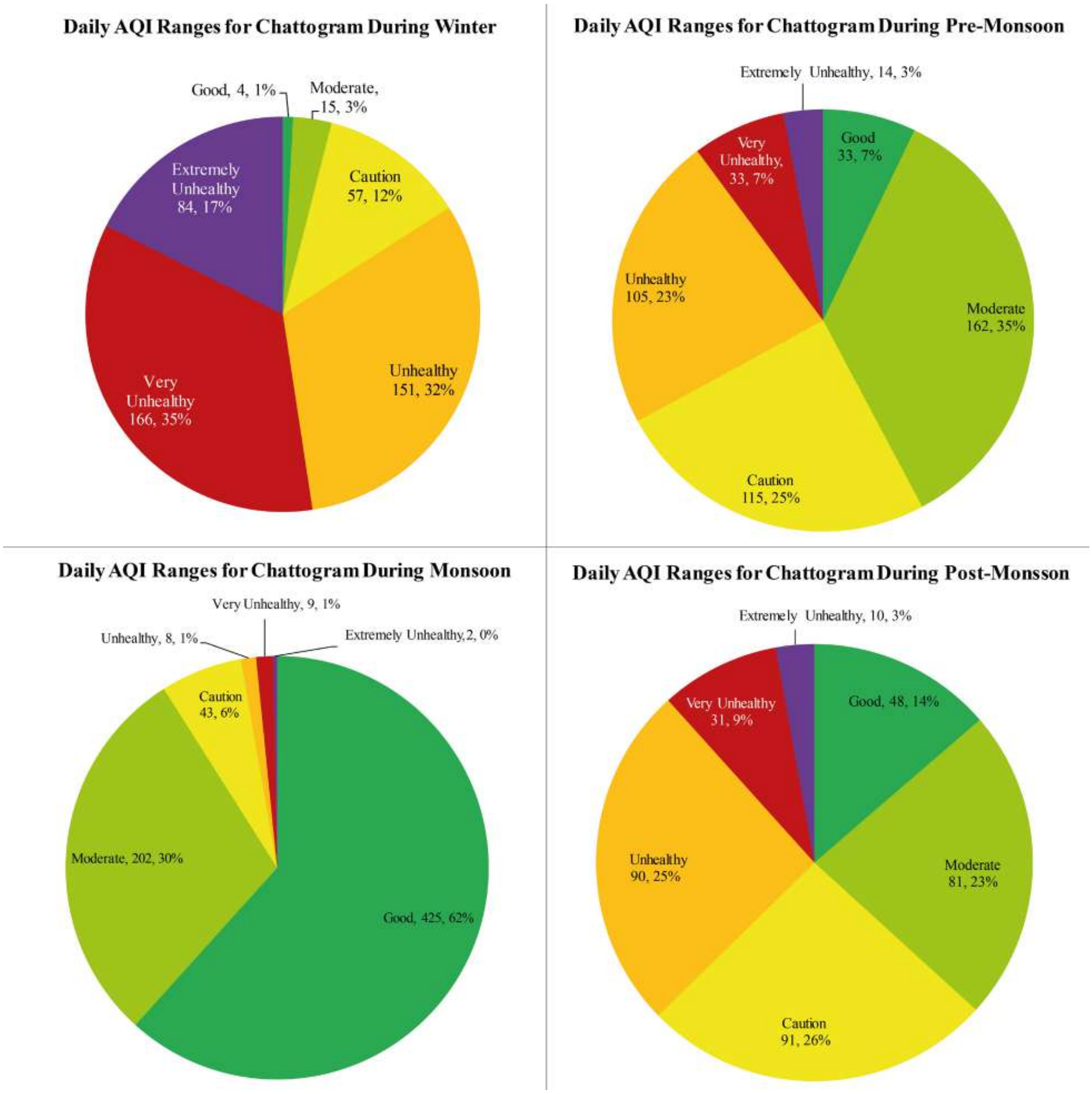

Fig. 3. The ranges of daily AQI for Chattogram

Fig. 3 illustrates the ranges of daily AQI for Chattogram. In the winter, the percentages of AQI classes A, B, C, D, and F were, respectively, 1%, 3%, 9%, 20%, 37%, and 30%. Pre-Monsoon AQI class A, B, C, D, E, and F percentages were 14%, 42%, 26%, 14%, 3%, and 1%, respectively. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 37%, 50%, 12%, 1%, 0%, and 0%, respectively. The percentages of AQI classes A, B, C, D, E, and F during Post-Monsoon were 6%, 14%, 18%, 37%, 19%, and 6%, respectively.

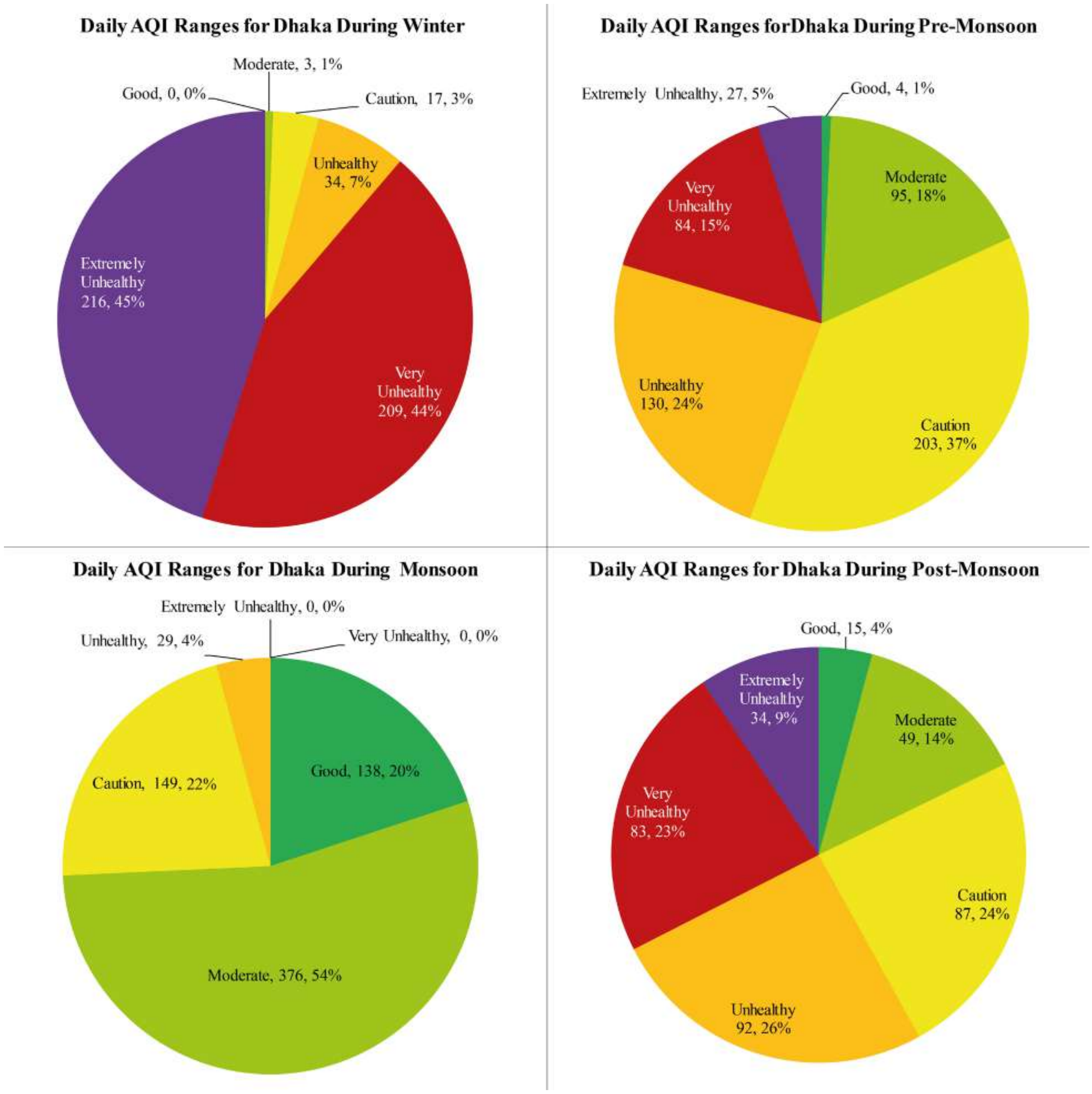

Fig. 4. The daily AQI range for Dhaka

Fig. 4 illustrates the daily AQI range for Dhaka. In Winter, the percentages of AQI classes A, B, C, D, E, and F were, respectively, 0%, 1%, 3%, 7%, 44%, and 45%. The percentages of AQI classes A, B, C, D, E, and F prior to the monsoon were 1%, 18%, 37%, 24%, 15%, and 5%, respectively. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 20%, 54%, 22%, 4%, 0%, and 0%, respectively. The percentages of AQI classes A, B, C, D, E, and F during Post-Monsoon were 4%, 14%, 24%, 26%, 23%, and 9%, respectively.

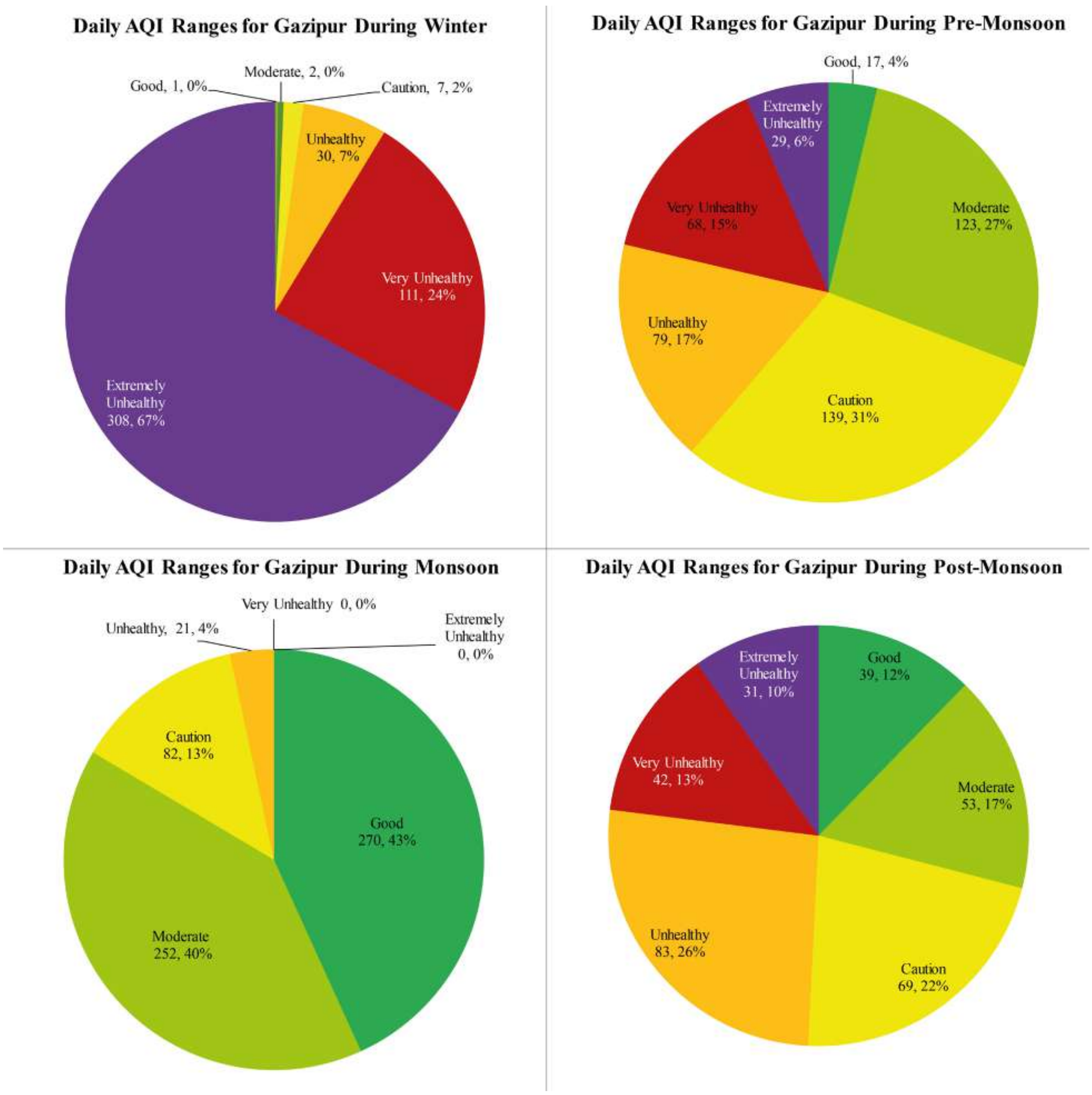

Fig. 5. The ranges of daily AQI for Gazipur

Fig. 5 illustrates the ranges of daily AQI for Gazipur. During the Winter, the percentages of AQI classes A, B, C, D, E, and F were, respectively, >1%, >1%, 2%, 7%, 24%, and 67%. The percentages of AQI classes A, B, C, D, E, and F prior to the monsoon were 4%, 27%, 31%, 17%, 15%, and 6%, respectively. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 43%, 40%, 13%, 4%, 0%, and 0%, respectively. In Post-Monsoon, the percentages of AQI classes A, B, C, D, E, and F were 12%, 17%, 22%, 26%, 13%, and 10% respectively.

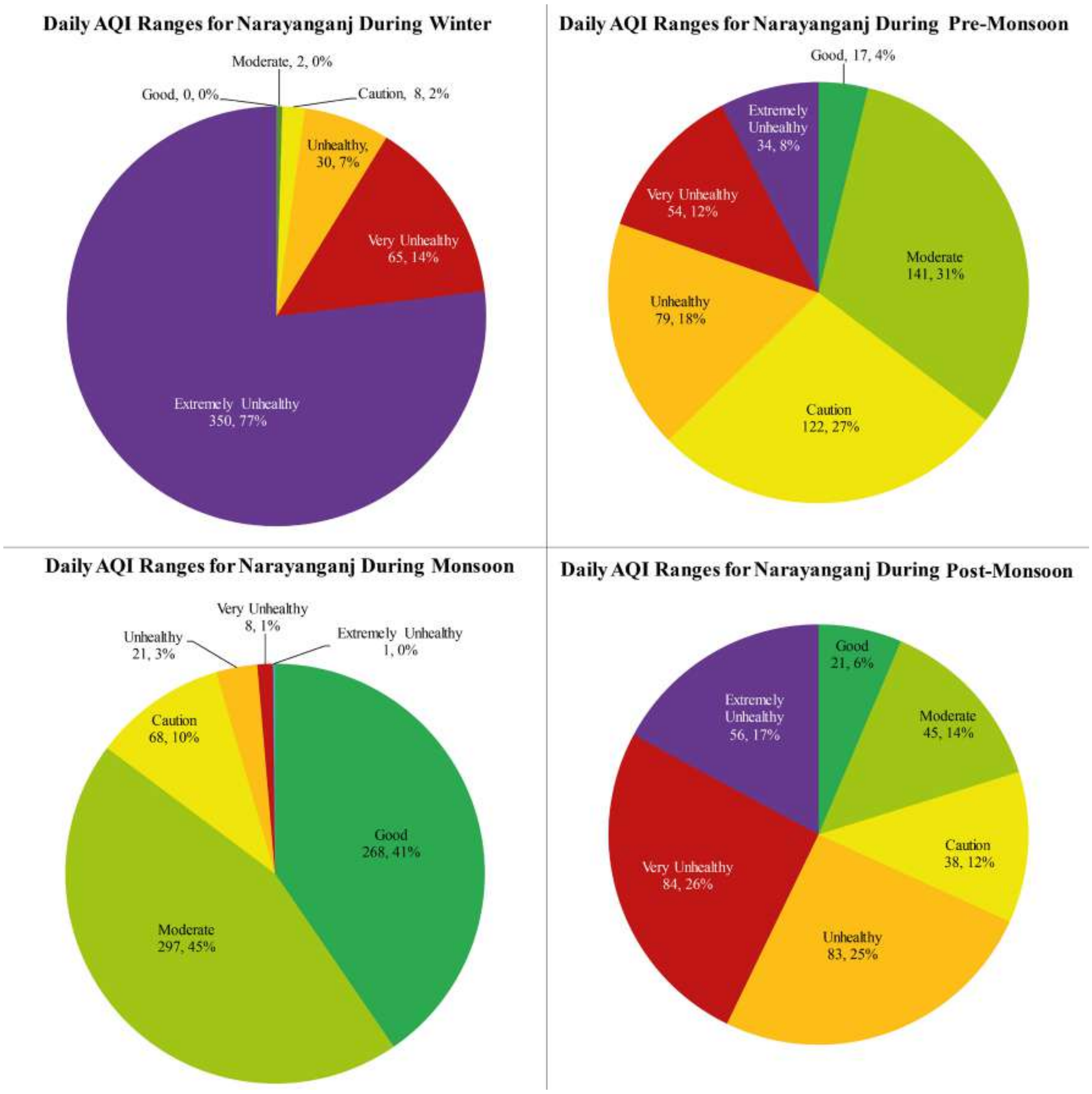

Fig. 6. The ranges of daily AQI for Narayanganj

Fig. 6 illustrates the ranges of daily AQI for Narayanganj. In the winter, the percentages of AQI classes A, B, C, D, E, and F were respectively 0%, >1%, 2%, 7%, 14%, and 77%. In the pre-monsoon period, the percentages of AQI classes A, B, C, D, E, and F were, respectively, 4%, 31%, 27%, 18%, 12%, and 8%. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 41%, 45%, 10%, 3%, 1%, and >1%, respectively. The percentages of AQI classes A, B, C, D, E, and F during Post-Monsoon were 6%, 14%, 12%, 25%, 26%, and 17%, respectively.

Fig. 7 illustrates the ranges of daily AQI for Sylhet. In Winter, the percentages of AQI classes A, B, C, D, E, and F were, respectively, 1%, 6%, 19%, 43%, 26%, and 5%. The percentages of AQI classes A, B, C, D, E, and F during the pre-monsoon period were 18%, 35%, 20%, 22%, 5%, and >1%, respectively. The percentages of AQI classes A, B, C, D, E, and F during the Monsoon were 63%, 32%, 5%, 0%, 0%, and 0%, respectively. In Post-Monsoon, the percentage of AQI classes A, B, C, D, E, and F were 18%, 36%, 31%, 13%, 2%, and 0% respectively.

Fig. 7. The ranges of daily AQI for Sylhet

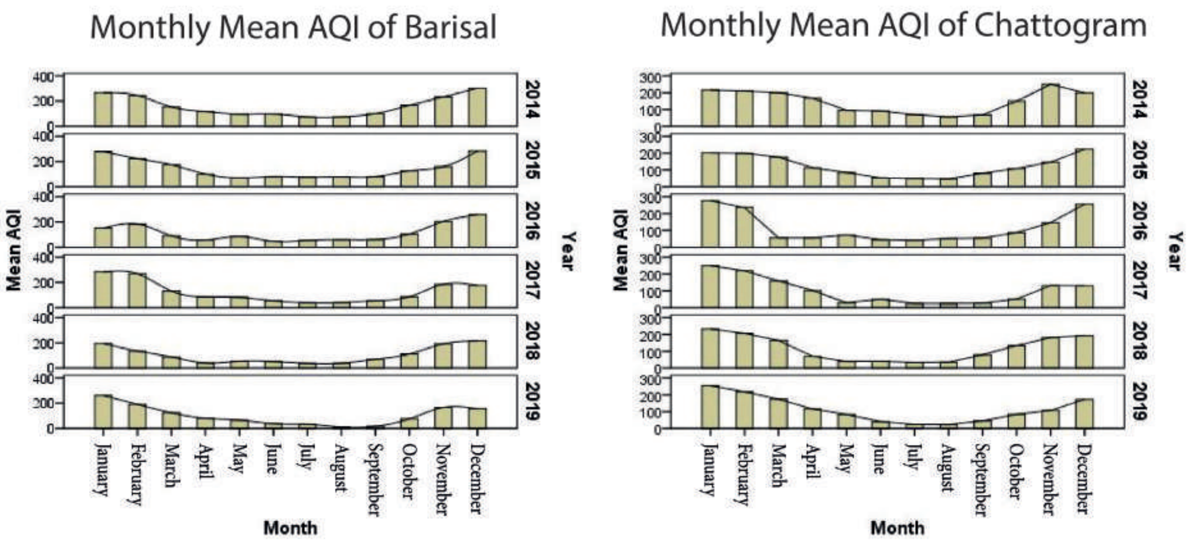

Fig. 8. The monthly mean of AQI in (a) Barisal; (b) Chattogram; (c) Dhaka; (d) Gazipur; (e) Narayanganj; (f) Sylhet stations of CAMS in Bangladesh from 2014 to 2019

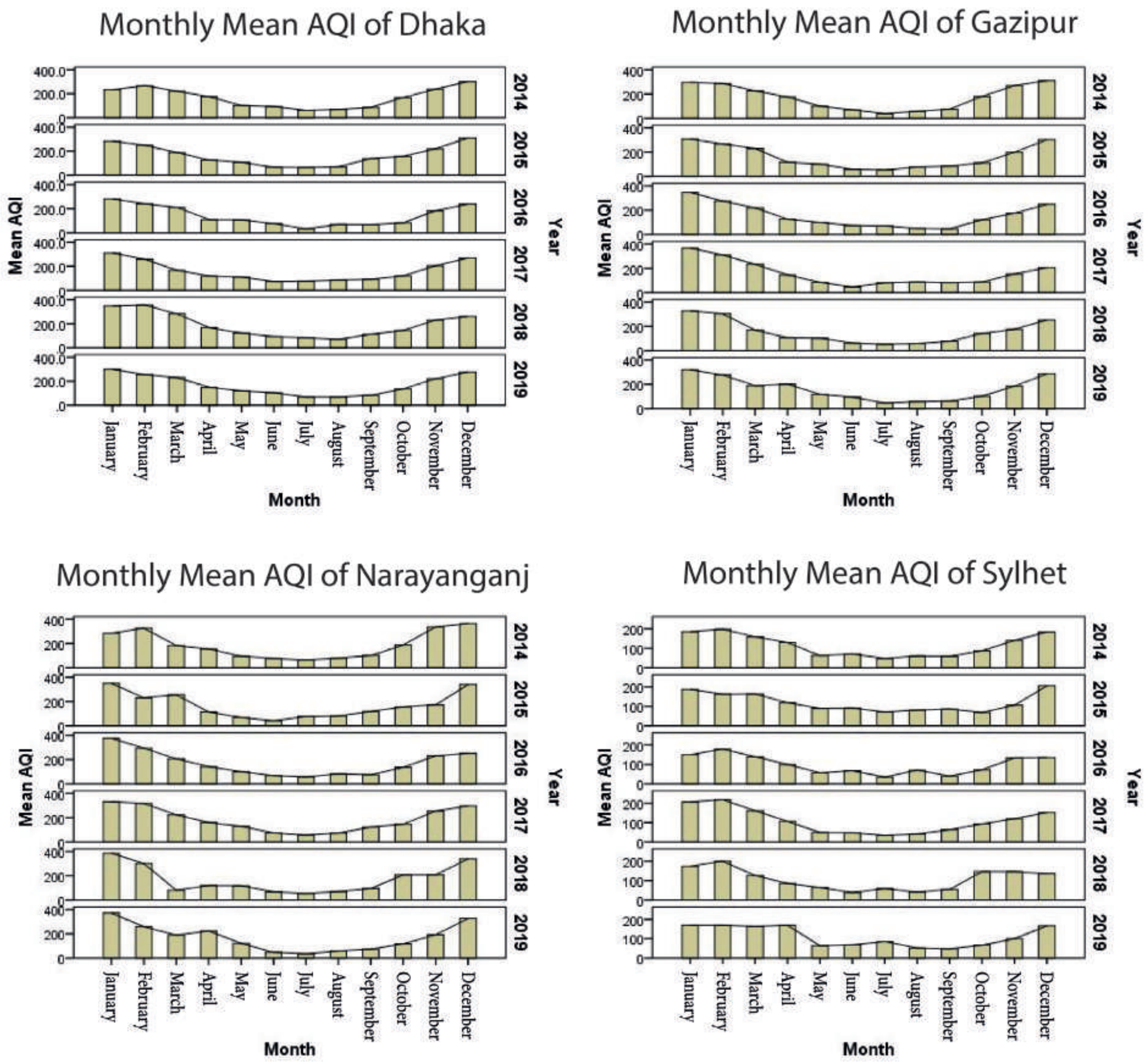

Fig. 8. The monthly mean of AQI in (a) Barisal; (b) Chattogram; (c) Dhaka; (d) Gazipur; (e) Narayanganj; (f) Sylhet stations of CAMS in Bangladesh from 2014 to 2019

Fig. 8 shows the monthly mean of AQI in (a) Barisal; (b) Chattogram; (c) Dhaka; (d) Gazipur; (e) Narayanganj; (f) Sylhet stations of CAMS in Bangladesh from 2014 to 2019. It shows the monthly variations of AQI values between 0-500 and the mean AQI was between 200 to 300 above. The mean annual AQI of the six locations reached its peak and lowest points in 2014 and 2016, respectively, according to data from the six-year observing time, although the air quality in 2018 showed some indications of decline. Dhaka's AQI was worse than that of the other five locations indicating that the air pollution there is more severe. The overall trajectory of the AQI for each and every one of the monitoring sites, the peak is seen to occur throughout the winter (between December and February). Conversely, during the monsoon of July through September, the lowest AQI readings are recorded. Peak pollution periods include the summer (March–June) and the post–monsoon months (October–November). Because there is more particulate matter in the air during the dry season, concentrations were greater than, whereas, in rainy season, particulate matter is dropped or settled in the ground due to rain or water droplets.

Table 3. Comparison of Season and AQI Across All Stations Using One-Way ANOVA (Analysis of variance)

Barisal Station					
	Sum of Squares	*df*	*Mean Square*	F	Sig.
Between Groups	321774.158	3	107258.053	68.196	.000
Within Groups	106950.015	68	1572.794		
Total	428724.173	71			
Chattogram Station					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	294852.342	3	98284.114	64.402	.000
Within Groups	103775.441	68	1526.109		
Total	398627.783	71			
Dhaka Station					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	416457.535	3	138819.178	90.300	.000
Within Groups	104537.240	68	1537.312		
Total	520994.775	71			
Gazipur Station					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	539320.396	3	179773.465	117.163	.000
Within Groups	104338.355	68	1534.388		
Total	643658.751	71			
Narayanganj Station					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	638363.919	3	212787.973	110.162	.000
Within Groups	131348.299	68	1931.593		
Total	769712.218	71			
Sylhet Station					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	142549.565	3	47516.522	57.447	.000
Within Groups	56244.897	68	827.131		
Total	198794.462	71			

The findings from the application of one-way ANOVA on the AQI owing to station variation are shown in Table 3. For Barisal, the computed F values were 68.196, 64.402 for Chattogram 90.300 for Dhaka, 117.163 for Gazipur, 110.162 for Narayangonj and 57.447 for Sylhet. The change in AQI concentrations depending on station is significant at P 0.05, according to Table 3. The F value was determined to be highly significant, indicating that the AQI significantly varies in all six locations because of to the various atmospheric conditions.

Fig. 9 express value of R^2 is 0.8672, 0.8173, 0.9098, 0.9214, 0.8753, 0.8843 for Barisal, Chattogram, Dhaka, Gazipur, Narayanganj, and Sylhet respectively. The percentage of the dependent variable's variance attributable to the independent variable was highest (92.14%) in Gazipur. The result shows that there is a positive relation between $PM_{2.5}$ and AQI for all stations and all year. It has been indicated that rising AQI values correspond to rising $PM_{2.5}$ concentrations. On the other side, AQI levels will also decline when $PM_{2.5}$ concentrations fall. It also demonstrated a strong relationship between the Air Quality Index and $PM_{2.5}$ [14].

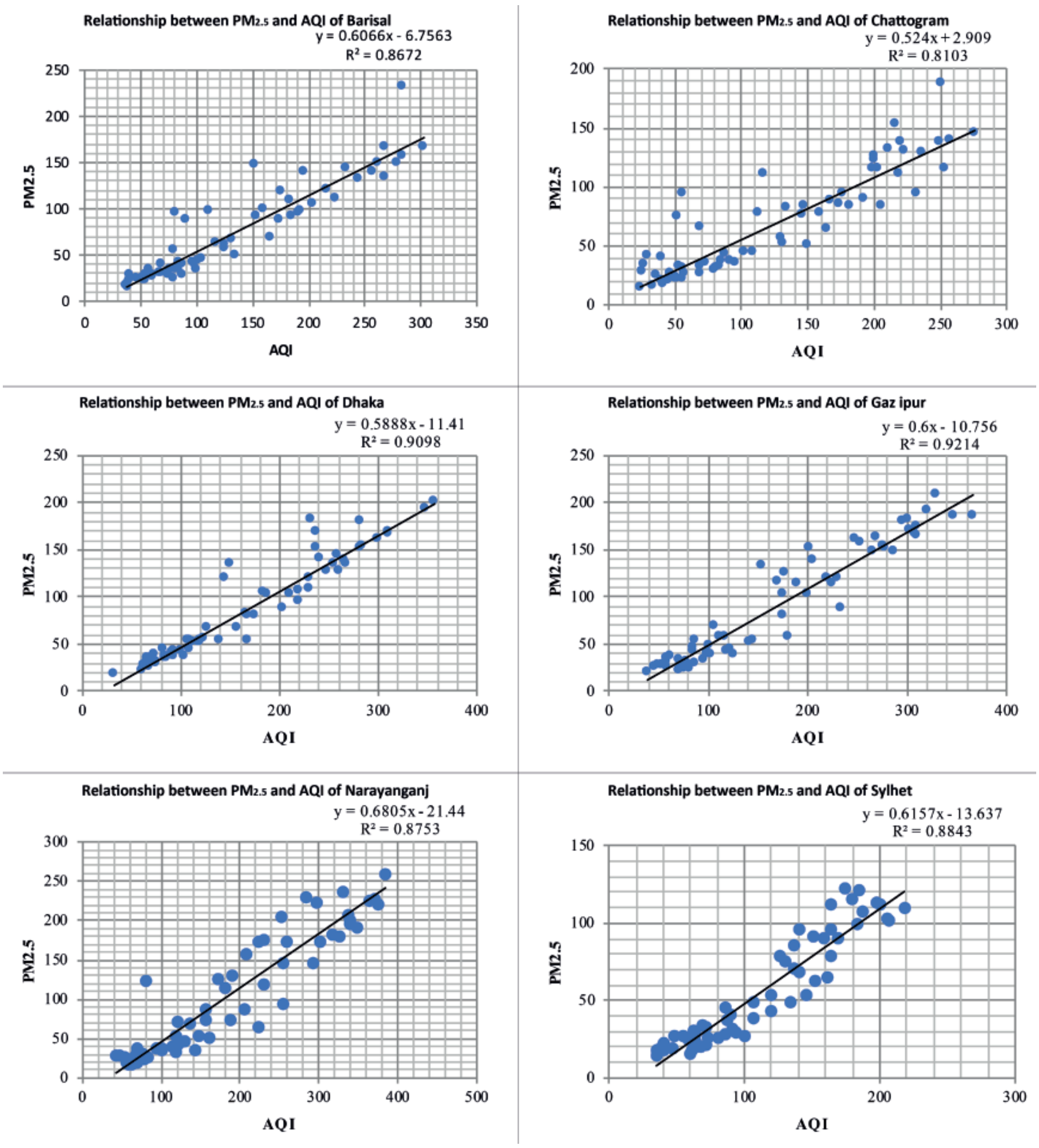

Fig. 9. Value of R^2 for Barisal, Chattogram, Dhaka, Gazipur, Narayanganj, and Sylhet

Discussion

The above result shows AQI classes in different seasons from 2014 to 2019. The AQI levels of six cities are in descending order as follows: Winter>Pre-Monsoon>Post-Monsoon>Monsoon. It reveals that all stations' air quality throughout the Winter season was at an alarmingly high level. Many reasons were responsible for this arising pollution. The most relevant causes were less vegetation cover, drying up of water bodies, burning biomass increased to warm up the body, use of heaters, no rainfall, colder air mass doesn't rise, and leaf burning [21]. On the other hand, Winter was the season for crops harvesting and then processing for marketing, and finally burning the waste [24]. It was one of the major reasons for the rising AQI. Additionally, the state of the air was hazardous to children, patients, and older people during the pre-monsoon season, which had the second-worst air quality [21]. The monsoon had the best air quality of the four seasons, whereas the post-monsoon had a more moderate level [25]. In Monsoon, enough rainfall increased the waterbody which diluted air pollutants. Less use of heaters, decreased crop wastage burning activities, less biomass burning, increased vegetation cover, warm air mass was lighter and rise easily, etc. were the common factors of decreased AQI in Monsoon period [26]. Extremely Unhealthy air was found in Narayanganj (77%), Gazipur (67%), and Dhaka (45%) out of 6 Districts (9 stations). Analysis of observation data during a period of six years (2014 to 2019), the six cities' Good AQI rankings were as follows: Sylhet (554 Days), Barisal (510 Days), Gazipur (327 Days), Chattogram (314 Days), Narayanganj (306 Days), and Dhaka (157 Days). Among them, Sylhet had best and Dhaka had worst air quality. It was determined that the majority of the AQI class was unhealthy and extremely unhealthy. It is clear that because of to a congested population, industrialization, expanding transportation, and extensive construction, Dhaka's air quality did not improve at all over the six years of evaluation. But the air quality in Sylhet and Barishal was excellent due to forestation, mountains, enough rainfall, many rivers just across both cities. decreased pollutants from the air. If people are exposed to this unhealthy air for a long time, they might be suffered from several kinds of respiratory diseases.

Conclusion

AQI percentages from daily measurements in various severity classes may provide a more thorough understanding of seasonal and yearly fluctuations than averaged data. In contrast to the interpretation of the national air quality standard, the air quality data interpretation via the AQI system demonstrates a more thorough assessment of the air quality. The research demonstrates that AQI values provide a precise representation of the air quality when analyzing data for various health categories over the course of a year's time. With good AQI, Sylhet and Chattogram are considered to be the least polluted cities. In Narayanganj (77%), Gazipur (67%), and Dhaka (45%), respectively, Extremely Unhealthy air was observed. Winter used to be the worst AQI season, but now it's summer, and starting in 2014, $PM_{2.5}$ concentrations have risen at all sites. The result indicates a positive relationship between $PM_{2.5}$ and AQI for all stations and years, with a r^2 value greater than 0.877. When P value of 0.05 the statistical analysis reveals a substantial correlation between the AQI values for all stations. According to the data that was analyzed, Bangladesh underwent significant development changes between the years 2014 and 2019. Because to urbanization, industry, an increase in the number of motor vehicles, a lack of awareness among the general population, the use of fuels with poor environmental performance, and weak environmental legislation, the air quality in

Bangladesh and other developing countries has been steadily deteriorating over the past several decades.

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Competing interests

The authors declare no competing interests.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors."

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