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AS3.1
Aerosol Chemistry and Physics (General Session)

Long Term Variability Trends Study Of Black Carbon Mass Concentration Levels Associated With $PM_{2.5}$ In The Megacity Of Lahore, Pakistan

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Background

- Air pollution is one of the **five major threats** to sustainability of life on Earth. The atmosphere is being loaded with pollutant gases, particulate matter and aerosols every moment due to burning of fossil fuels, biomass and industrial activities *(Zimmermann, 2016).*
- **Particulate matter** consists of very small particles of complex mixtures that may contain dust particles, organic chemicals, acid fumes, salts, and black carbon *(US-EPA, 2018).*
- **Black Carbon (BC)** particles are an important and distinct atmospheric pollutant that is produced during incomplete combustion of biomass and fossil fuel. Black carbon particles are accumulated in atmosphere and depending on climatic condition are transferred at regional and global level.
- Black Carbon particles are removed from atmosphere through scavenging by rain droplet as wet precipitation or dry deposition to the ground. Lifetime of BC in atmosphere is ranged between **4 to 12 days**.
- It is estimated that annually **8×10^9 kg** of BC is emitted into atmosphere, that has major contribution in global warming after the greenhouse gases (*Bond et al., 2004*).
- BC concentration in atmosphere ranges from less than **1 ng/m^3** in polar region to **tens of µg/m^3** in urban regions (*Shen et al., 2020*).
- It is estimated that troposphere **holds 20Tg of suspended dust particles nearly half of total aerosol mass** (*Kalluri et al., 2017*).
- Global distribution of black carbon indicates high concentrations in **South and Southeast Asia, central Europe**, and **Eastern regions of USA** (Figure 1).

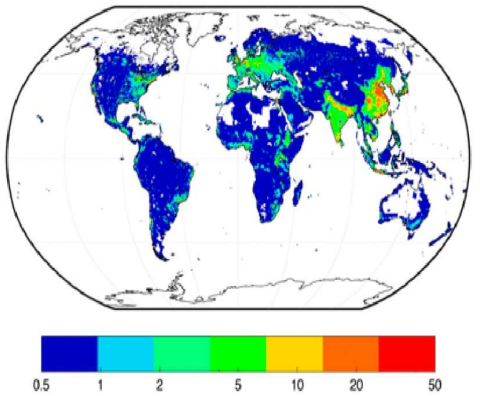


Figure 1. Global Black Carbon Emissions

Source: World Health Organization, (2018)

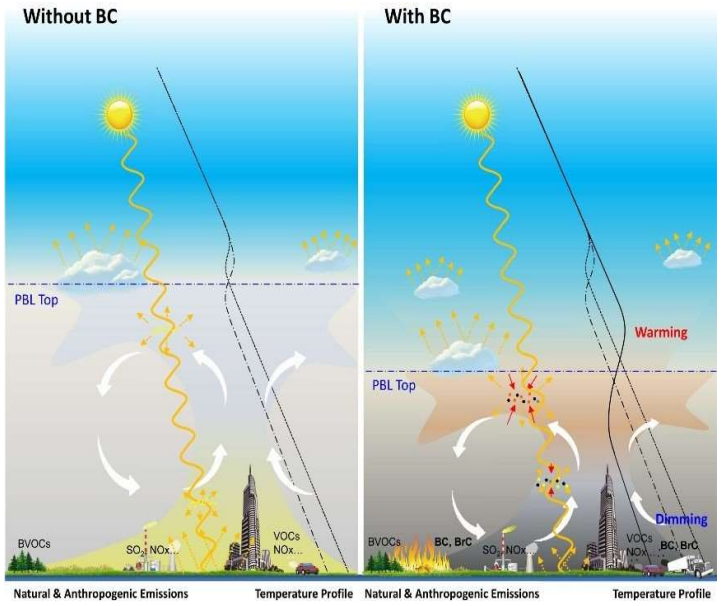
Major Environmental Concern

Strong Radiative Absorption of radiation >Causing Climate Change

- Radiative forcing estimated double of greenhouse effect due to CO_2 (*Guo et al., 2020).*
- Most important global warming factor along CO_2 and methane (*Bond et al., 2013).*

Dome Effect due to BC Particulates

- Due to strong absorption of radiation with short wavelength heating occurs at 1-2 Km altitude.
- This stops radiation to reach lower area and causes cooling.
- Due to induced temperature inversion planetary boundary layer (PBL) lowers.
- Dome effect causes local pollution aggravation and poor visibility *(Ding et al., (2016)*



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Major Environmental Concern

Catalyst for Acid Rain

- BC particles act as catalytic sites in oxidation of SO_2 to sulfate resulting in acidic precipitation (*Blanco-Alegre et al., 2019*)

Glacier melting

- BC due to strong absorption changes glacier surface albedo
- Results induced glacier melting due to change in heat balance

Figure 3. Black Carbon particles deposited on glaciers cause melting at exorbitant rate. (*CCAC, 2018)*

Motivation

- Pakistan on the list of most prone countries under threat of **pollution hazards** and **climate change**
- Every year **22,000** inhabitants die to outdoor air pollution and **28,000** deaths due to exposure of indoor air pollution (*WHO, 2021*)
- Lahore is the **second largest city** of Pakistan and capital of Punjab Province with more than **11 million inhabitants**.
- Lahore is an industrial & commercial hub of the country and is being rapidly expanding.
- City is bearing emissions of 4.92 million vehicles (*Punjab Bureau of Statistics, 2017)*
- **Insufficient data** available to establish BC variation trends in urban atmosphere of Lahore

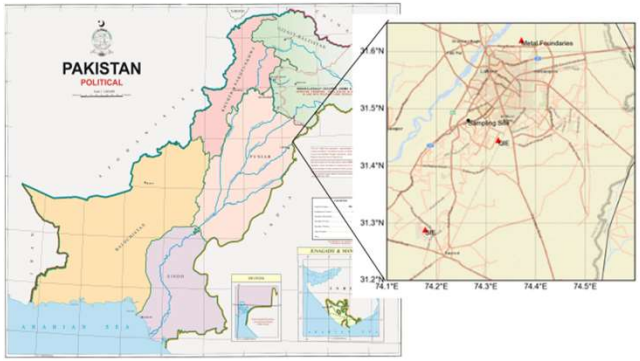

Figure 4. The city is located at 31°32′59″N 74°20′37″E and area is flat with altitude of 217 meter above sea level.

Objectives

1. Mean daily, monthly, seasonal, diurnal BC trends
2. BC and metrological parameters i.e., temp, RH, WS, precipitation correlation
3. Impact of lockdown during pandemic of Covid-19 over BC mass concentration

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Measurement Technique

- Measurements were performed by utilizing the unique optical absorption property of black carbon particles, using the aethalometer
- Light of specific wavelength (880nm) is passed through filter tape with spot of aerosols collected after passing air through filter tape (Figure 5.). Change in optical light intensity is studied simultaneously from unladen (reference spot) and aerosol loaded spot-on filter tape. Equation 1 is used to derive BC mass concentration.
- Measurement data was processed to obtain mean values and diurnal pattern of BC concentration for daily, monthly and seasonal basis.
- To investigate linear relationship between BC mass concentration and metrological parameters like temperature, wind speed, relative humidity, and precipitation, Pearson correlation analysis was also performed.

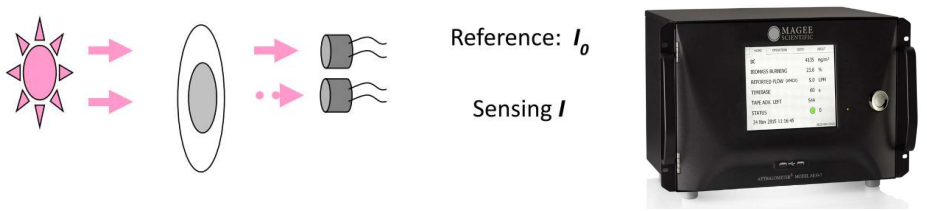


Figure 5. Attenuation of Optical Absorption by BC mass on filter tape and Aethalometer (Magee Scientific, 2016)

$$BC = \frac{S_A(\triangle ATN(\lambda)/100)}{F(1-\zeta)\sigma_{air}C(1-k\triangle ATN(\lambda))\triangle t}$$

Eq. 1

Where;

S_A is spot area, *ATN* is optical attenuation, F is flow rate

ζ is leakage factor

σ_{air} = mass absorption cross-section

C = multiple scattering parameter

k = compensation parameter

λ = 880nm, t = time duration.

(Rigler et al., 2020)

Daily Mean BC

- Mean BC levels similar for both years.
- Standard deviation value shows BC mass concentration variance more pronounced during 2019 as compared to 2020.

Year	Range	Mean	Standard Deviation
2019	0.66-148.45	11.77	13.54
2020	1.55-50.52	11.17	8.67

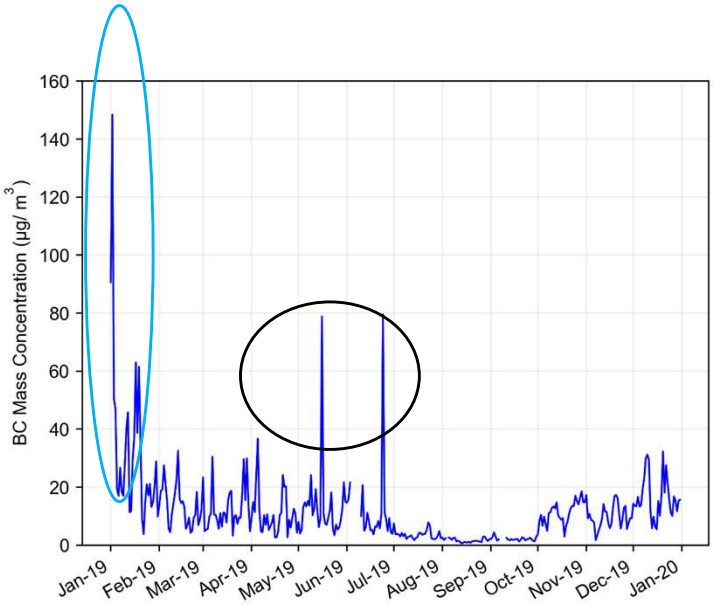


Figure 6. Daily BC Mass Concentration 2019

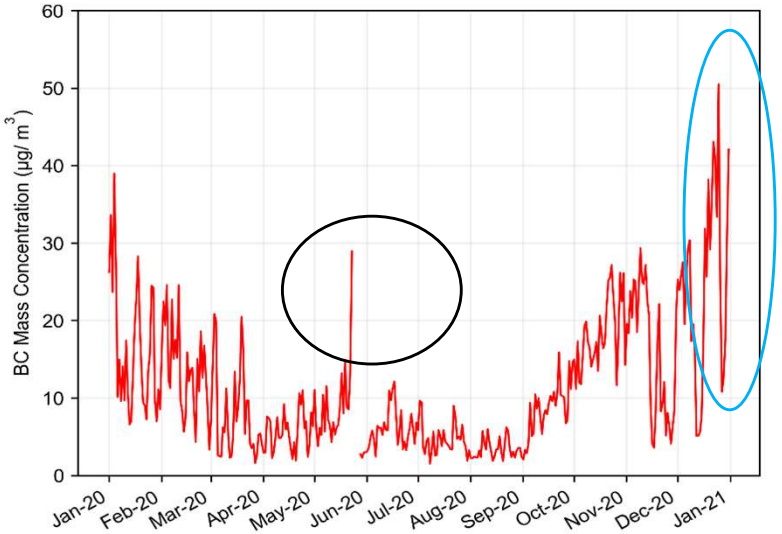


Figure 7. Daily BC Mass Concentration 2020

Result and Discussion

Monthly Mean BC

- Monthly averaged values ranged between **1.62 and 32.64 µg/m³**
- Highest **32.64±60.64 µg/m³** for January 2019, Lowest **1.62±1.21 µg/m³** for August 2019

	2019				2020			
Month	Mean	SD	Min	Max	Mean	SD	Min	Max
Jan	32.64	60.64	1.7	1042	15.95	12.7	1.91	84.06
Feb	13.56	12.63	1.24	106.36	13.75	11.05	0.39	62.31
Mar	12.47	12.78	1.08	98.8	7.81	9.4	0.485	57.66
Apr	10.87	12.365	0.915	91.2	5.73	5.64	0.44	45.37
May	13.21	27.4	0.506	424.9	7.513	7.35	0.54	49.71
Jun	11.88	29.88	0.706	394.42	6.15	5.08	0.51	37.12
Jul	3.63	2.4	0.57	18.26	4.75	3.84	0.58	27.97
Aug	1.62	1.21	0.254	10.71	3.4	2.37	0.3	19.77
Sep	2.15	1.29	0.41	12.36	8.64	7.13	1.26	56.56
Oct	11.15	8.91	0.674	48.17	18.22	13.04	1.5	76.23
Nov	9.71	7.4	0.98	47.03	15.92	13.17	0.84	96.78
Dec	16.21	10.76	0.713	77.52	24.64	18.86	1.77	98.5

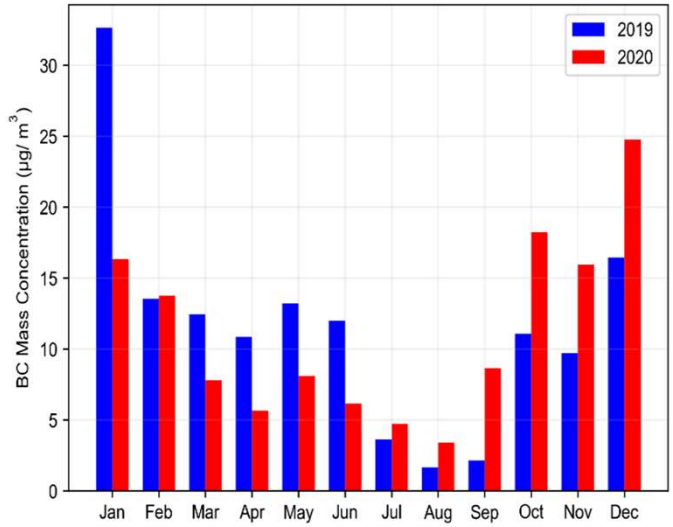


Figure 8. Monthly mean BC Mass Concentration 2019-2020

Seasonal Mean BC

- Distinct seasonal variability
- **winter>autumn>spring>summer**
- Highest **21.1±18.2 µg/m³** (winter 2019)
- Lowest **4.7±2.3 µg/m³** (summer 2020)
- Lower values of BC during summer months to be associated with scavenging effect of **precipitation during monsoon**
- Elevated levels of BC mass concentration during colder months due to **increase in fuel burning for heating and crops residue burning**.
- Suppression in planetary boundary layer (PBL)
- Poor dispersion due to decrease in turbulence of air during winter months

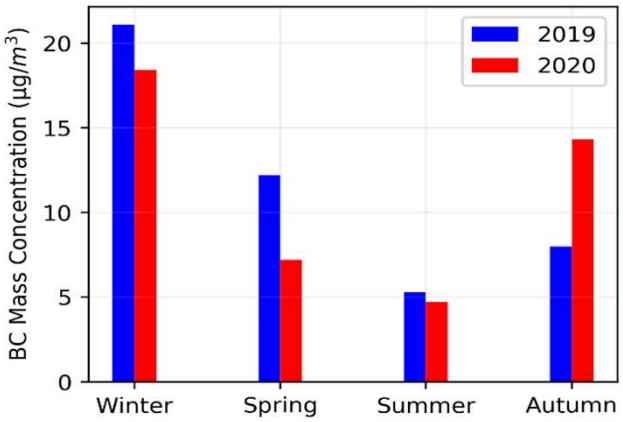


Figure 9. Seasonal mean BC mass concentration 2019-2020

Season	Range	Mean	Standard Deviation
Winter-19	3.8-148.4	21.1	18.2
Winter-20	3.4-50.5	18.4	10.2
Spring-19	2.6-78.8	12.2	9.7
Spring -20	1.6-29.0	7.2	4.7
Summer-19	0.7-79.6	5.3	9.1
Summer -20	1.5-12.2	4.7	2.3
Autumn-19	1.3-18.5	8.0	5.1
Autumn -20	2.1-29.4	14.32	7.0

Weekdays Mean BC

- Weekdays mean BC variability ranged between **10.1** and **13.2 µg/m³.**
- Concentration levels increasing during working days from **Mondays** to **Thursdays**
- Lower concentrations on weekends
- Black carbon mass concentration during working days were found lower for 2020 as compared to 2019 that may be attributed to the effect of lockdown.

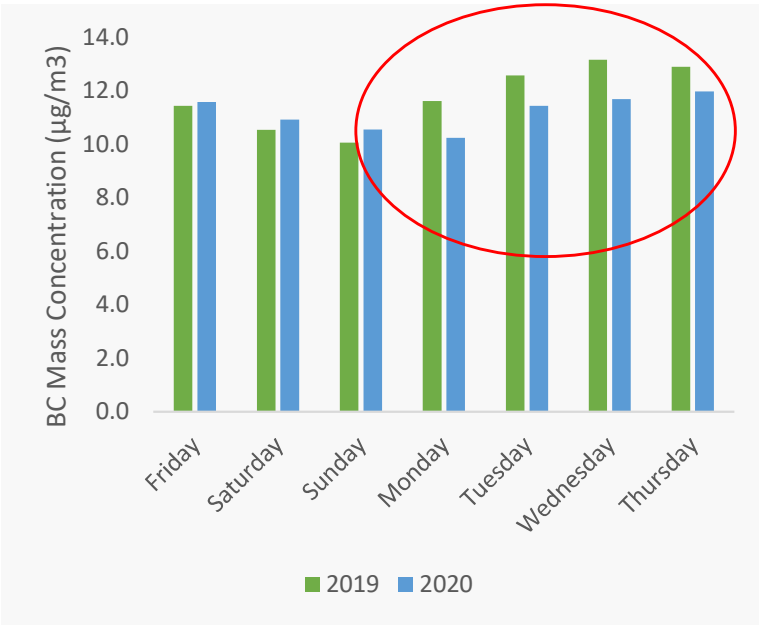


Figure 10. Weekdays Mean BC concentration

Diurnal Mean BC

- Pronounced bimodal diurnal variation curves for both study years 2019 and 2020.
- Entire period of study shows maximum BC concentration during **early morning** (06:00 to 09:00) and again increasing from evening (17:00) with **highest value** until **late night** (22:00 to 00:00).
- During daytime BC value starts decreasing between 08:00 to 09:00 with **lowest value** at **afternoon** (14:00-15:00).
- Similar trend reported by Xiao et al. (2020).

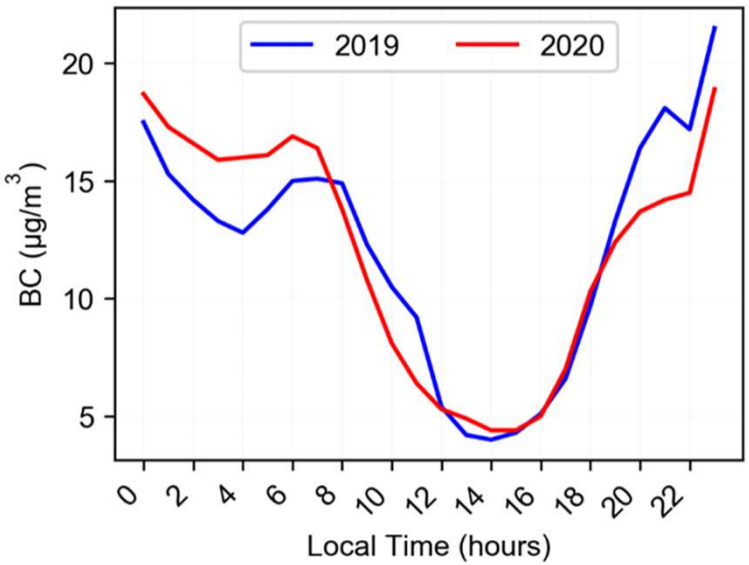
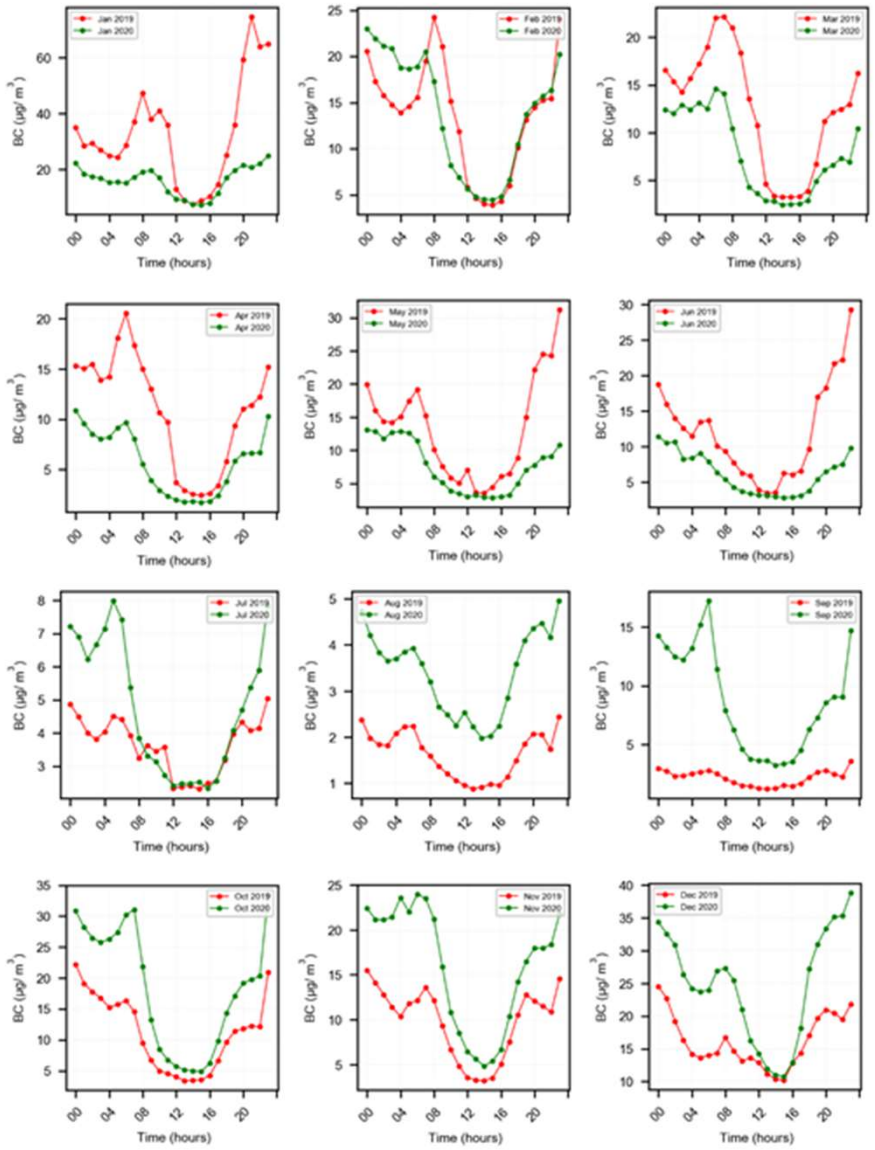


Figure 11. Diurnal variability trends

Diurnal mean BC (monthly)

- Monthly diurnal BC mass concentration variability has similar **bimodal trends** for all months.
- Variability more pronounced during colder months.
- Diurnal trend line during April to June 2020 showed **weaker variability** resulting in decline of local emissions due to lockdown.
- For month of September 2019 similar trend appeared that may be associated with **wet precipitation** of BC during rainy season.
- October to December 2020 more pronounced diurnal variability as compared to same months of 2019 with lesser rain episodes .



Result and Discussion

Mean BC and Meteorology

- Black carbon mass concentration variability during 2019 and 2020 is studied against metrological parameters like temperature, wind speed, relative humidity, and precipitation (Figures 13 & 14).
- Correlation coefficient R values (-0.46 to -0.63) showed temperature and wind speed have moderate negative association (Figure 15). Relative humidity between 50-70% seems favorable for BC mass concentration accumulation in atmosphere.
- Precipitation episodes (monsoon) during both years appeared with minimum BC concentration showing strong role of rains in wet deposition of BC particles.
- Decline in rainy days during October to December 2020 as compared to 2019, BC mass concentration accumulated to higher levels comparatively.
- Cape et al. (2012) and Blanco-Alegre et al. (2019) have also studied similar association

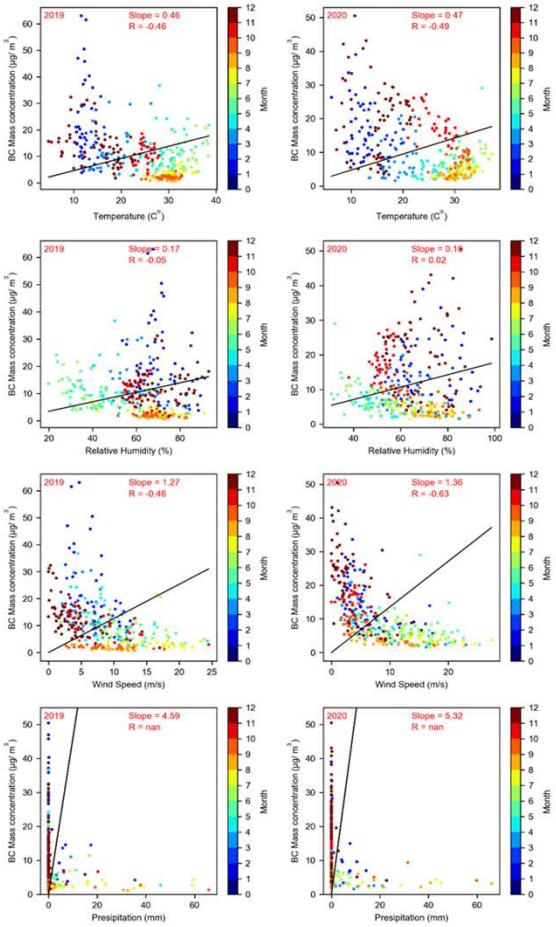


Figure 15. Correlation between BC Mass Concentration and Metrological Parameters (temperature, Relative Humidity, Wind Speed Precipitation

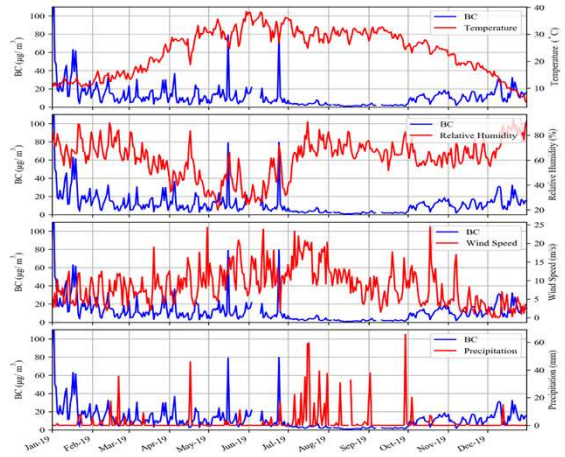


Figure 13 BC Mass Concentration 2019 and Metrological Parameters

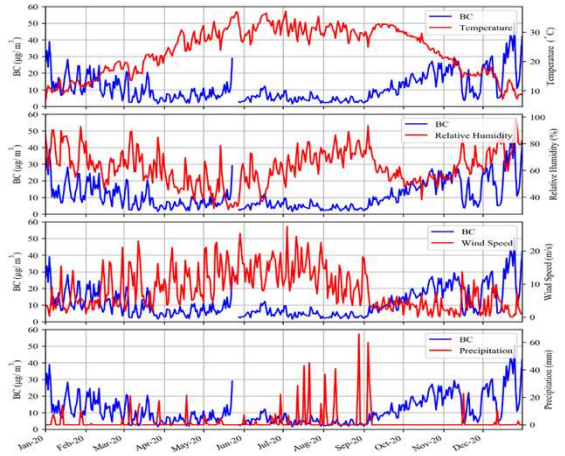


Figure 14 BC Mass Concentration 2020 and Metrological Parameters

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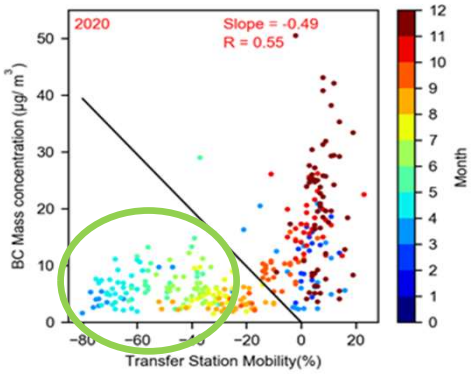
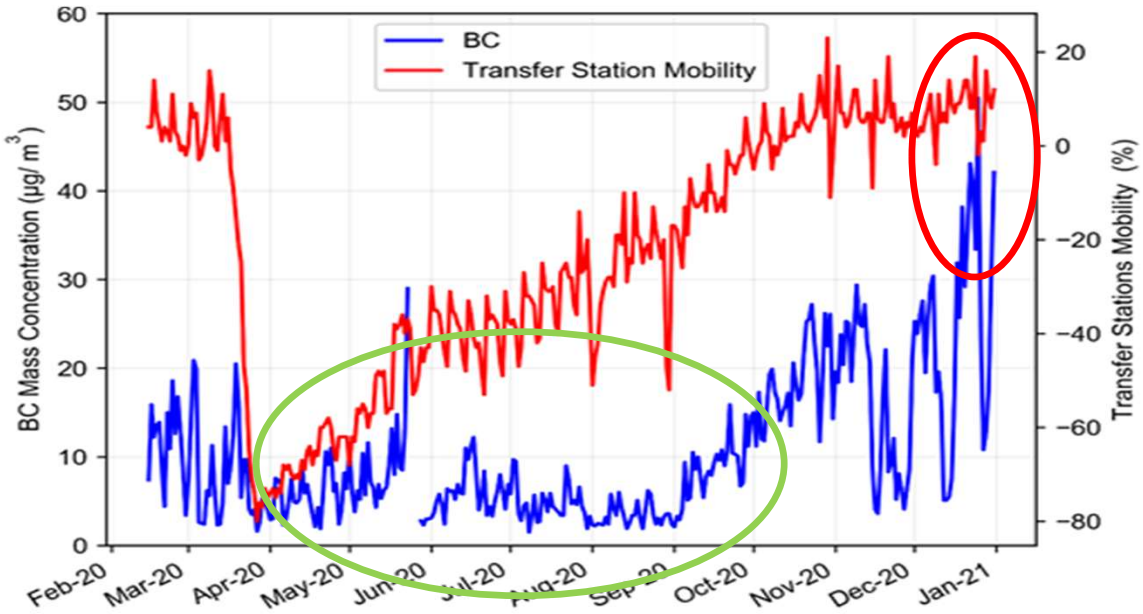
Mean BC and Lockdown

- ✓ Lockdown in different phases during March to July 2020
- ✓ Trend of BC mass concentration and Google mobility data for transit stations during year 2020 showed moderate correlation with **R** value of **0.55**, *Google LLC, (2021)*
- ✓ BC concentration levels showed decline of **38, 48, 39, and 48%** for **March** to **June 2020** respectively as compared to the same months during 2019



Lock Down Month	2019 BC (µg/m³)	2020 BC (µg/m³)	Change %
Feb	13.6	13.8	1.45
Mar	12.5	7.8	-38
Apr	10.9	5.7	-48
May	13.2	8.1	-39
Jun	12.0	6.1	-49
Jul	3.6	4.7	31



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Mean BC and Lockdown

- **Pre-lockdown** and during **lockdown BC** mass concentration is compared.
- BC mass concentration reduction is estimated to ~ **50%.**
- Similar trends studied by Goel et. al. (2021)

Period	Date	Mean BC (µg/m$^{3)}$	Change
Pre-Lockdown (PL)	1 Feb to 18 Mar	11.7	baseline
Lockdown-1 (L1)	19 Mar to 4 Apr	6.7	↓ (-43%)
Lockdown-1 (L2)	5 Apr to 14 Apr	5.5	↓ (-53%)
Lockdown-1 (L3)	15 to 24 Apr	6.0	↓ (-48%)
Lockdown-1 (L4)	25 Apr to 09 May	6.7	↓ (-42%)
Unlock-1 (UN1)	10 May to 31 May	8.4	↓ (-28%)
Lockdown (smart)	1 to 30 Jun	6.1	↓ (-47%)
Unlock-2 (UN2)	1 to 27 Jul	5.0	↓ (-58%)
Lockdown (smart2)	28 Jul to 1 Aug	3.1	↓ (-73%)
Unlock-3 (UN3)	2 to 9 Aug relaxed for Eid	3.1	↓ (-73%)
Lockdown Lifted	10 Aug to 31 Dec	14.9	↑ (27%)

Conclusion

- Annual baseline of BC concentration **11.77 µg/m^3** (2019) **and 11.17 µg/m^3** (2020) relatively higher as compared to **WHO (10 µg/m^3)** guideline although BC being only fraction of total **$PM_{2.5}$**.
- Monthly mean BC values varied between **3.4 µg/m^3** (August 2019) to **32.6 µg/m^3** (January 2020).
- BC mass concentration has **moderate negative correlation** with ambient temperature and wind speed.
- Lower levels of BC during monsoon months show **wet deposition** of BC aerosols.
- **Distinct diurnal** variance with bimodal peaks and decline in BC mass concentration (~50%) during lockdown indicates local emission contributions associated with **motor vehicles, commercial** and **industrial** activities

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