Synergic relation between urban pollution island and meteorological parameters over urban heat island for the city of Hyderabad during lockdown

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Abstract
Covid-19 marked as a deadly pandemic hit the world in the early 2020's. Stringent measures were implemented, to contain the virus. India first implemented lockdown on 25/03/2020 for 21 days (phase 1) and extended to 4 phases till 31 May 2020. During this lockdown, all socio-economic activities are put to a standstill. This resulted in a drastic improvement in the air quality. Although this being a temporary phenomenon, it plays a crucial role in studying atmospheric gases. This study makes an attempt to analyze the effect of the pollutants - PM2.5, PM10 and ozone combined with meteorological parameters - Relative Humidity (RH), Solar Radiation (SR) on the Ambient and Surface Temperatures (AT and LST).

The data from 23 March 30 June for the consecutive years 2019 and 2020 have been considered. Each parameter is then plotted to study the trend for both the years and percentage differences are also calculated. To evaluate the synergic relation between the parameters, multiple linear regression analysis is done for each pollutant with meteorological parameters. Observations show a reduction in all the pollutants during the lockdown period. RH showed an increasing trend. Atmospheric temperature is reduced by 6^{o}C to 10^{o}C whereas the LST is noticed to increase by 3^{o}C to 5^{o}C.

Keywords: Lockdown, PM2.5, PM10, Ozone, RH, LST.

Introduction

In early 2020, the world was hit by a deadly pandemic, the SARS Coronavirus, casing all socio-economic activities to a standstill. Stringent measures were taken all over to contain the virus. A nationwide lockdown has been implemented In India in 4 phases (25th March to 31st May) followed by unlock phase (1st June – 30th September). During the initial phase of lockdown, all human activities are paused causing restrictions to the moment of vehicular traffic and shutdown of the majority of industries resulting in a drastic improvement in the air quality all over the world. Although this is a temporary phenomenon, it has a significant role in studying atmospheric gases.

Urbanization and economic development are inextricably linked. Improved standard of living, increased opportunities and availability of resources make urban environments more ideal for living. According to a UN report published in 2018, 55% of the world's population resided in urban and by 2050 about 68% of the world's population tends to live in urban settings.[20] Urbanization with its positive effects comes with a set of complications including decreased air quality, increased land use and resource consumption. This shift in the land surface from natural to impervious results in a higher Bowen ratio, lower albedo and larger energy storage around the urban areas leading to warmer temperatures compared to surrounding suburbs causing urban heat island.

On the other hand, anthropogenic activities like burning fossil fuels from industries, transport, construction and other human activities result in higher concentrations of pollutants in the urban atmosphere causing the Urban Pollution Island.[3,5]

UHI raises the heat stress on the urban dwellers whereas UPI increases pollution exposure affecting human health.[7] For the formation and accumulation of high concentrations of pollutants, certain meteorological conditions are required.[4] Parameters like a well-defined boundary layer, solar radiation, RH, wind speed are major factors influencing the urban air quality[15] as they may have an impact on the dispersion process, removal mechanisms and formation of atmospheric particles.[9] A synergic relation exists between UHI, UPI and meteorological parameters.

Many studies have been conducted on these parameters individually but very few studies have shown their combined effect. The warmer temperatures in the UHI promote aerosol dispersion to the higher atmosphere by increasing turbulent mixing.[18] Reduction in urban temperature decreases turbulent mixing leading to higher near-surface PM10 concentrations.[6] Higher aerosol concentrations scatter more SR (short wave) to space contrarily trap the infrared radiation emitted by the earth surface as longwave radiations.[2,14]

Moreover, higher RH causes dilution and agglomeration of aerosols i.e. by aqueous phase reactions and gas-particle partitioning.[17,23] Ground-level ozone is produced photochemically under the influence of solar radiation. High temperature increases the amount of VOC's (Volatile Organic Compounds) in the air. These hydrocarbons are evaporated in high temperatures, consequently making a double contribution to ground-level ozone formation.[12] In this study, the synergic relation between UPI and

meteorological parameters is analyzed by using the multiple linear regression approach for the city of Hyderabad.

Study Area

Hyderabad, the capital of Telangana State is the third largest metropolitan region in India, occupying an area of 7,257 sq km.[11] The city is surrounded by 3 districts namely Rangareddy, Medchal-Malkajgiri and Hyderabad Urban. Hyderabad lies approximately between the latitudes 17° 25'N to 17° 55'N and longitudes 78°23'E to 78°63'E, with an altitude of 536m above sea level. It has a tropical wet and dry climate. Temperatures of the city may exceed 40° during summer months (April to June) and in winters temperatures vary from 14° to 28° (December to January).

A report given by Global Metro Meter stated that it as the 5th largest economy in the country.[8] The city is an industrial hub with large to small scale industries from defense, pharmaceutical and manufacturing, logistics, packing etc. in both private and public sectors. Hyderabad having the highest GDP in the State also ranks top in pollution emissions. In this study, the Hyderabad Urban area [217sq km, Greater Hyderabad Municipal Corporation] and 10 peripheral municipalities totaling the area to 680 km^2 are under the Hyderabad Urban Development Authority (HUDA) are considered.

Lockdown in India

As a measure to eradicate the virus, the Government of India implemented phase-wise lockdowns. In the first phase (25th March – 14th April), any movement was strictly prohibited limiting 1.36 billion population to their houses. In the second phase of lockdown (15th April – 3rd May), essential businesses including dairy, farming and farm supplies, cargo transportation, banks and public works offices are allowed to run and from 29th April, permissions were given for interstate movement. In the third phase of lockdown (4th May – 17th May), the country was divided into 3 zones, Red representing highly affected areas, Orange representing areas with less cases and green representing regions with no cases in the last 21 days.

Some relaxations were made in the green zones but the containment zones were kept closed. In the fourth phase of lockdown (18th May to 31th May), red zones were further divided into buffer zones. Followed by Unlock phases, wherein Unlock-1 (1st June to 30th June), all activities were allowed in a phased manner outside the containment zones.

Data and Methods

For LST, two daily products MOD11A1 and MYD11A1 version 6 aboard the EOS NASA's TERRA and AQUA satellites are used. These are available at 1 km spectral resolution in a 1200km by 1200km grid. The data is retrieved using a generalized split-window algorithm. The version 6 data is further refined for cloud contamination and topographical variations[21] and has a standard deviation of <0.5 K.[22] The data has temporal resolutions of 10:00 am to 11:00 am during the day and 10 pm to11pm during the night for terra and 1:00 pm to 2:00 pm during the day and 1:00 am to 2:00 am during the night for AQUA.

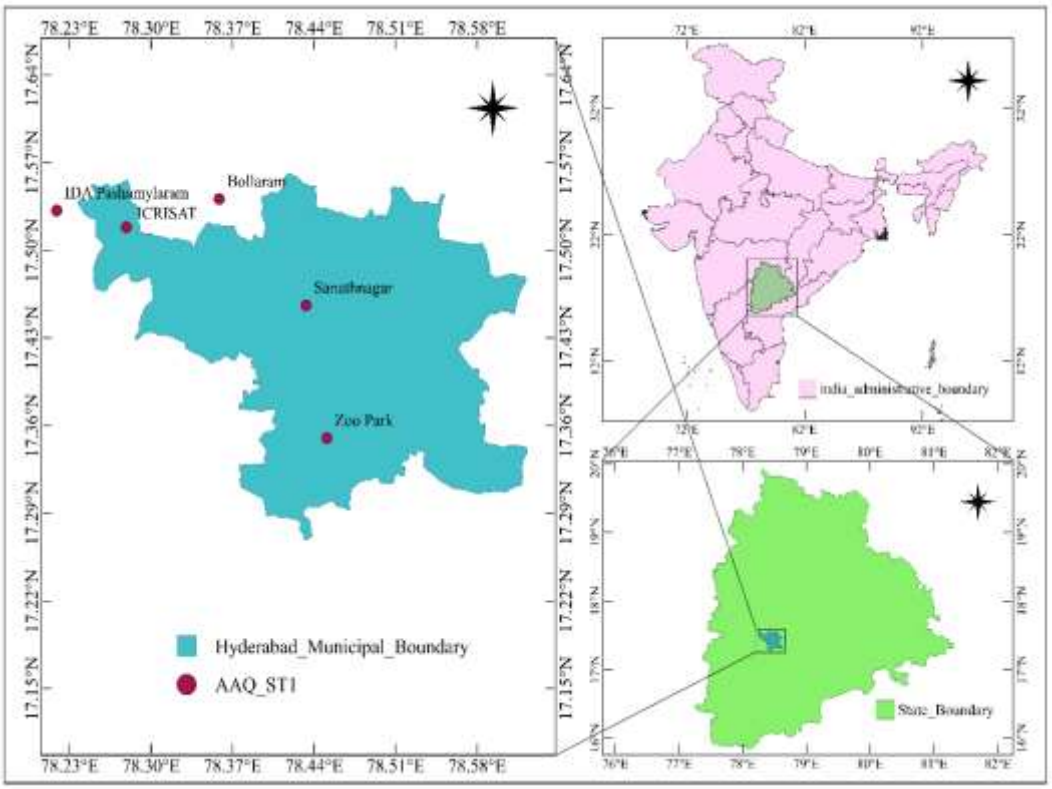


Fig. 1: Study Area Boundary Map showing CAAQM Stations.

Two data products have been considered in this study to compensate for the missing data. Hourly averaged near-surface data for 5 stations located in and around Hyderabad city have been taken from CPCB's Continuous Ambient Air Quality Monitoring Stations (CAAQMS) portal. The pollutant concentrations for PM 2.5, PM10, Ozone and Meteorological parameters- Solar Radiation, RH and Atmospheric temperature were collected for the period 23th March – 30th June on consecutive years 2019 and 2020. The data is quality controlled by removing any constant values and outliers. These parameters are then coupled with the LST data for the corresponding time period making a total of 4 data sets a day i.e. 2 sets for day and 2 for the night.

The mean value is calculated combining for both day and night separately. Multiple linear regression analysis is carried out for each pollutant with meteorological parameters and LST (Table 1). For clear data visualization, each parameter is then plotted to study the trend (Table 2) and percentage differences are also calculated (Refer Table 3).

Table 1
Regression analysis (R^2) on pollutant with temperature (LST and Ambient temperatures), SR and RH at 5 CAAQMS.

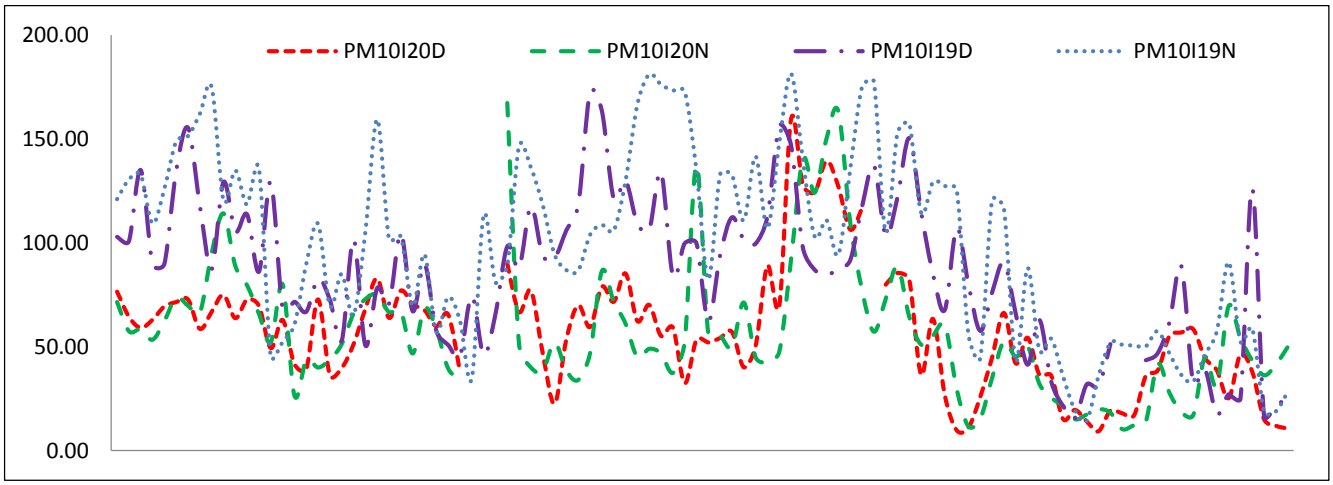
Pollutant	CAAQS				
	ICRISAT	Pashamailaram	Bollaram	Sanath nagar	Zoo Park
PM10	0.474	0.399	0.394	-	0.471
PM2.5	0.325	0.405	0.347	0.279	0.457
Ozone	0.476	0.41	0.428	0.637	0.534

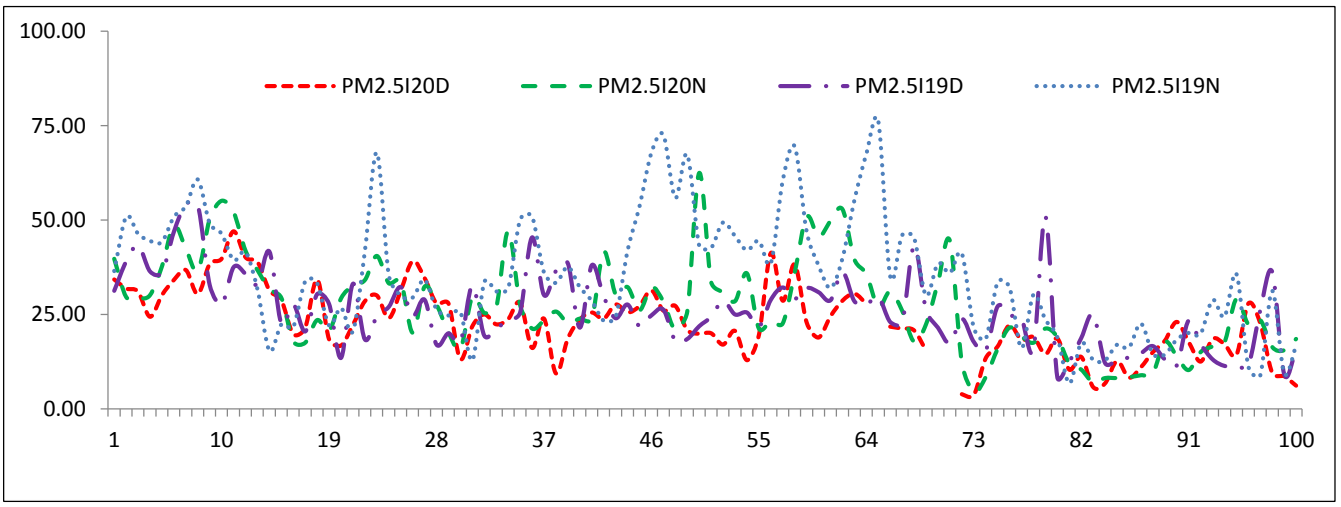
Table 2
Mean and Standard Deviation at 5 CAAQMS for consecutive years 2019 and 2020 (23rd Mar – 30th June).

	Mean						*Standard Deviation*				
Pollutant/ Env. Parameters	***ICRISAT***	***Pasha-mylaram***	***Bollaram***	***Sanath nagar***	***Zoo PARK***		***ICRISAT***	***Pasha-mylaram***	***Bollaram***	***Sanath nagar***	***Zoo PARK***
PM10-20D	57.6	63.9	66.1	-	96.5		29.1	30.7	28.8	-	33.1
PM10-20N	56.9	63.7	64.8	-	81.5		31.9	28.7	33.6	-	34.2
PM10-19D	85.7	90.7	92.0	-	98.2		36.6	37.7	32.4	-	41.9
PM10-19N	99.2	96.0	106.5	-	106.5		44.9	41.5	40.4	-	42.4
PM2.5-20D	22.8	25.3	24.5	27.0	37.1		9.2	9.0	9.1	8.6	17.5
PM2.5-20N	27.2	28.5	29.8	30.1	37.2		12.2	12.6	12.2	12.1	15.9
PM2.5-19D	26.0	31.7	34.8	38.8	43.3		9.9	10.1	11.4	11.9	16.4
PM2.5-19N	35.1	38.2	44.0	45.0	51.4		15.8	15.5	15.4	15.2	18.6
Ozone -20D	27.4	31.6	26.6	51.6	25.5		10.0	16.9	8.5	17.7	9.0
Ozone -20N	17.4	21.0	18.4	29.6	19.9		6.3	11.7	6.4	10.8	5.2
Ozone -19D	64.3	31.5	37.1	53.5	62.2		17.5	10.4	12.0	16.8	17.8
Ozone -19N	35.9	18.1	21.8	21.4	31.0		15.8	7.2	8.9	8.6	10.7
LST-20D	42.3	45.0	43.5	41.7	40.5		3.7	4.2	3.8	3.8	3.6
LST-20N	25.0	24.3	26.3	27.1	26.6		2.4	2.2	2.1	2.2	1.8
LST-19D	42.9	44.6	43.1	41.4	40.1		3.6	3.7	3.7	3.3	3.4
LST-19N	25.2	24.3	25.7	27.6	26.4		2.0	2.1	2.2	1.9	1.6
AT-20D	28.9	29.9	26.7	33.9	33.9		4.0	2.6	4.3	2.6	3.8
AT-20N	25.6	25.1	23.4	28.5	30.9		3.9	1.7	3.9	1.9	5.5
AT-19D	35.7	35.4	33.7	34.6	35.2		2.3	2.8	2.5	2.2	2.9
AT-19N	31.2	30.0	29.3	29.0	29.8		1.7	2.0	2.3	2.1	2.1
SR-20D	370.1	674.3	232.8	496.0	220.4		87.3	145.9	138.8	127.8	101.6
SR-20N	20.7	3.4	17.6	2.2	8.6		0.4	0.5	1.0	0.4	1.7
SR-19D	404.6	723.7	354.0	506.1	312.5		64.7	134.1	63.1	122.1	51.5
SR-19N	22.8	6.0	16.2	2.1	1.9		2.4	0.1	0.7	0.2	0.3
RH-20D	49.5	44.6	48.8	43.5	47.0		11.5	11.0	14.4	9.8	12.6
RH-20N	62.5	56.9	59.2	55.2	63.4		11.6	11.6	15.4	11.5	12.6
RH-19D	44.0	38.4	40.3	38.1	40.2		9.0	10.1	10.7	8.6	8.9
RH-19N	56.2	49.7	49.9	49.3	54.4		10.1	10.9	11.2	9.8	9.4

Table 3
Mean Percent difference for the year 2020 over 2019 at 5 CAAQMS (study period 23rd Mar – 30th June)

Pollutant / Env. Parameters	*ICRISAT*	*Pasha-mylaram*	*Bollaram*	*Sanath nagar*	*Zoo PARK*
PM10-D	25.9	22.6	20.2	-	21.0
PM10-N	34.6	26.0	30.9	-	36.3
PM10-DN	30.3	24.3	25.6	-	28.6
PM2.5-D	9.4	16.2	25.8	21.5	10.4
PM2.5-N	13.2	17.2	26.4	24.6	20.9
PM2.5-DN	11.3	16.7	26.1	23.1	15.7
Ozone-D	54.0	-19.6	21.9	-0.2	56.0
Ozone -N	21.4	-41.2	-0.5	-68.7	25.7
Ozone -DN	37.7	-30.4	10.7	-34.5	40.8
LST-D	0.0	-1.4	-2.6	-1.0	-0.9
LST-N	2.5	-0.6	-1.3	0.0	0.1
LST-DN	1.3	-1.0	-1.9	-0.5	-0.4
AT-D	18.3	14.9	20.7	2.0	7.3
AT-N	17.6	16.3	20.3	1.4	3.1
AT-DN	18.0	15.6	20.5	1.7	5.2
SR-D	5.3	1.0	30.5	-28.5	28.5
SR-N	-	-	-	-	-
SR-DN	-	-	-	-	-
RH-D	-13.4	-18.8	-24.9	-16.9	-19.6
RH-N	-12.9	-16.9	-21.6	-13.9	-17.0
RH-DN	-13.2	-17.8	-23.2	-15.4	-18.3





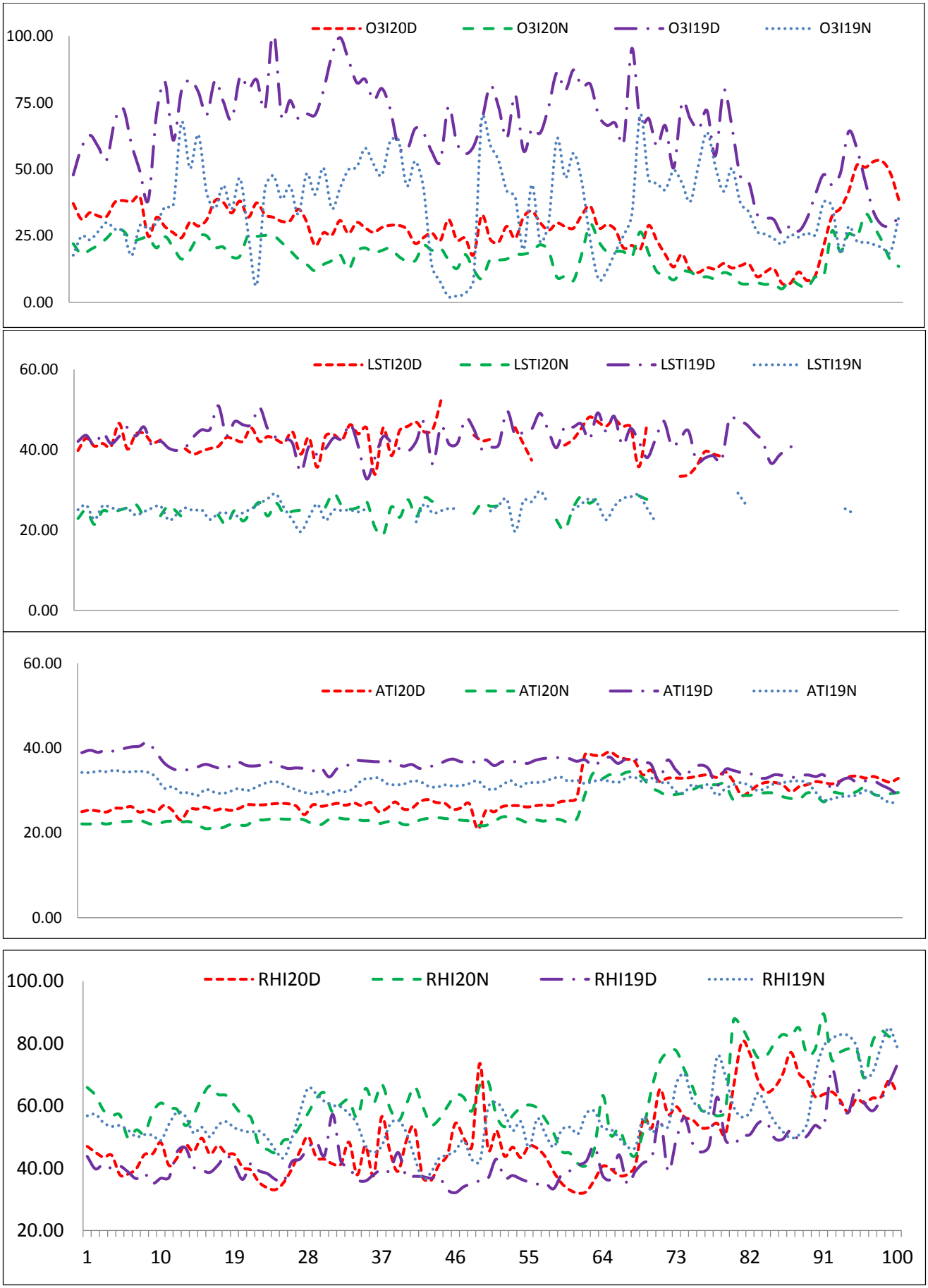


Fig. 2: CAAQMS ICRISAT trends of O3, LST, AT and RH for 2020 and 2019 ('23rd Mar – 30th June')

Results and Discussion

Increasing urbanization rapid industrialization elevated the pollutant concentrations and heat stress forming UPI and UHI. Both UHI and UPI are interrelated, so studying their combined effect will help us in understanding the atmospheric transformations in an urban area. With the emergence of Covid-19, the implication of lockdown resulted in a halt to all socio-economic activities. Drastic improvement in air quality throughout the country has been noticed during this period. Multiple regression analysis is carried out on each pollutant with temperature (LST and Ambient temperatures), SR and RH, as in table 1.

A positive linear relation has been noticed at all the stations. Ozone and PM10 show high R^2 values compared to PM2.5. R^2 for ozone at Sanath nagar is 0.637 representing high regression value and for PM2.5 at this station is 0.279 which is the lowest. The period of 23rd march to 30th June (i.e. 100 days) for the years 2019 and 2020 is considered as analysis period and the trend of the data is plotted (Fig. 2 shows the graphical representation of the data for station ICRISAT).

Table 2 shows the mean, standard deviation and percentage difference for each parameter where 'D' represents day values and 'N' represents night values for the consecutive years 2019 and 2020 to help visualize the data. For percentage difference, the positive value represents percentage decrease over the year 2019 while negative value indicates percentage increase in the pollutants during 2020. The stations Bollaram and IDA Pashmailaram are located outside the urban boundary, but as stations are located in industrial areas, not much difference has been noticed in the urban-rural areas.

A. Pollutants: The suspended particles in the atmosphere like dust, smoke, fumes, fly ash, soot, mist are the components of particulate matter. They are categorized by particle sizes as PM2.5 and PM10. PM has both human and natural sources. Combustion, construction and demolition activities release high PM quantities being the primary cause of emissions in cities. During the second week of lockdown consistent decrease has been noticed in both PM2.5 and PM10 till 3rd phase. In the 4th phase of lockdown, the concentrations of pollutants show an increasing trend due to partial relaxations. The unlock phase from 1st June is the start of monsoon season for Hyderabad; Relative Humidity during this period is increased.

The moisture in the atmosphere adheres to the PM (PM2.5 and PM10). These particles eventually grew larger causing dry deposition resulting in a decrease in PM concentrations. The aerosol concentrations during the night are relatively high than during the day for both the years 2019 and 2020 as in table 3 because lower temperatures and turbulences during the night reduce the atmospheric boundary layer affecting the dispersion of pollutants. Consequently, during the day, the temperature and turbulences are higher helping to boost the dispersion process.

B. Ozone: Tropospheric ozone is a secondary pollutant which at elevated concentrations (180 $\mu g/m^3$) is harmful to plants and other materials and also causes respiratory issues and other health concerns.[16] Ozone concentrations are lower during the lockdown for the stations except Sanathnagar and IDA Pashmylaram as in table 3. Ground-level ozone is produced photochemically through a complex series of reactions under the influence of solar radiation. When the oxides of nitrogen or VOC's (Volatile Organic Compounds) are exposed to SR, it forms ozone. These ozone molecules again when exposed to NO result in ozone scavenging. This being a continuous cycle helps in maintaining these concentrations under permissible limits in the atmosphere.

But in the lockdown period, the NO_x and VOC's decreased due to inactivity, making it not possible to further cannibalize the ozone already present in the atmosphere. Moreover, these stations are present in areas with high residences causing wind blockage. The wind speed noted at these stations is nearly less than 3m/s representing very less turbulences. This results in building up the ozone concentrations in these areas. As mentioned earlier, the month of June being the start of the monsoon, a decline in O_3 concentrations was noticed.

C. Meteorological parameters: Meteorological parameters play a crucial role in shaping the earth's atmosphere. There exists a relation between meteorological parameters and pollutants. Parameters like solar radiation, RH, wind speed and ambient temperatures determine the pollutant dispersion, dilution and vice versa. SR and wind speed did not show any significant changes in trend for both the years. Schwarz et al[19] stated that the changes in air quality in the recent decades have increased noticeably the amount of SR reaching the surface of the earth.

This further increases the amount of radiation absorbed by the earth increasing the land surface temperature. An increase in LST of 1°C to 5°C has been noticed in the lockdown period in all stations except for ICRISAT (table 3). All CAAQM stations observed high RH during the lockdown and with night concentrations being much higher. The reduction in aerosol concentrations significantly increases the low cloud coverage, thereby increasing the RH. Consequently, the AT also decreased unlike LST as the greenhouse gases are lower, reducing the heat holding capacity of the atmosphere.

D. Effect on urban temperatures: The amount of SR entering the earth is re-radiated back into space over a certain time interval. This is called the Surface Energy Balance (SEB) concept. However, this varies with time, area and synoptic conditions.[10] The SEB of an urban area is different from the surrounding rural areas. Low albedo materials, higher urban canopy layer and impervious surfaces absorb the SR making urban areas hotter, thereby forming Urban Heat Island. Several factors also affect the temperatures by causing complex interactions[1,13] which are been analyzed in

this study. The UHI is measured by the increase in both LST and ambient temperatures.

During the lockdown, ambient temperature is noticed to be lesser compared to the previous year. Reduction in anthropogenic activities led to a decline in PM and ozone concentrations. As clear skies do not interact with solar radiation, very little radiation is absorbed by the atmosphere, thereby reducing the ambient temperatures. Contrarily the amount of radiation entering the surface is increased, which is absorbed by the earth's surface increasing the land surface temperatures. Points with high RH show a decline in ambient temperatures.

Generally, low temperatures tend to increase the humidity as in figure 2. As temperature decreases atmospheric boundary layer or the mixing heights tend to decrease, thereby accommodating more water vapor within less depth. The surface of the earth also absorbs SR depending on the type and properties of the surface called as the land surface temperature.

This absorbed SR is again re-radiated back into the atmosphere during the night in the form of long-wave radiations, maintaining a balance in the temperature. LST for all the stations is higher at 3^o to 5^o during lockdown except ICRISAT. The station ICRISAT is surrounded by vegetation and barren land; these surfaces generally reflect the radiation. This is one of the reasons why rural and near urban areas are cooler than urban areas.

Conclusion

The impact of lockdown on urban pollution island, meteorological parameters and urban heat island for Hyderabad city has been studied. A synergic relation exists between UPI, meteorological Parameters and UHI. Their interaction in the atmosphere will affect the climate. During lockdown AT reduced by 6^o to 10^o but LST increased by 3^o to 5^o. The multiple regression analysis shows higher R^2 values indicating a positive interaction. Only a few researchers have studied the combined effect of the 3 components on the urban atmosphere. With rapid urbanization, we are noticing changes in the environment.

Presently we are evidencing the effects of climate change as reduced immunity, water problems, pollution-causing adulteration in all the available resources, natural calamities, etc. Studying these atmospheric interactions aids in the comprehension of weather patterns. Further research needs to be carried out to address the present issues, interpret the long-term effects and find feasible solutions for sustainable development of the urban areas to increase the quality of life and lifestyle.

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