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Impact of COVID-19 Lockdowns on Air Quality in the South Asian Region

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Abstract— Air pollution has become a common problem in most urbanized cities in the world. South Asia is a pollution hot spot since most countries in the region qualify to be categorized as developing nations with poor monitoring and control of industrial-related pollution. The recent outbreak of the COVID-19 pandemic led many countries to lock-down to control the spread of the virus. This resulted in the complete shut-down of most sources of industrial emissions and a heavy reduction in vehicular emissions. Accordingly, most South Asian countries witness a notable reduction in air pollution and significant improvement in air quality. This study measures and compares the change in pollution levels in the first six months of 2020 while using 2018, and 2019 as points of reference. The analysis includes an investigation of daily, weekly, and monthly trends of air pollution concentrating on PM2.5 levels in six countries of the region. Based on the observations of the analysis, significant factors affecting the level of change in air quality were identified. Most cities recorded significant change in the pollution level only after 30 days into the lockdown while the Source of pollution, topography, and location were identified as the main factors which affected the dispersion rate of pollution.

***Keywords**: air pollution, COVID-19, Sri Lanka, South Asia*

I. INTRODUCTION

Most countries in the south Asian region qualify as developing countries consisting of low or middle-income attributes. As history suggests the cost of development includes heavy adverse impacts on the surrounding environment. Air pollution and worsening of Air Quality have been a constant headache in the region. According to IQAir report on global air quality, 18 out of the top 20 most polluted cities in the world are from the South Asian region (AirVisual, 2019). According to expert research, most of the pollution in the region occurs in the form of particulate matter (Hopke *et al.*, 2008; Aryala *et al.*, 2009; Begum and Hopke, 2018). Particulate Matter (PM) refers to microparticles of solid pollutants if inhaled over long exposure periods could be of deadly results. It is identified that the PM originate mainly from industrial emissions and vehicular emissions (Ali and Athar, 2010; Seneviratne *et al.*, 2011; Gurjar, Ravindra and Nagpure, 2016). Initial research into PM dates back to the late 18th century and early 19th century (Brimblecombe, 1999). Researchers have identified that the major reasons for increased emission of PM through industrial and vehicular emissions are due to weak emission control regulations and primitive fuel types (Bekir Onursal and Gautam, 1997; Singh, V. *et al.*, 2020). World Health Organization defines 25 μg/m^3 as the standard exposure condition for 24-hour mean for PM2.5. The recent pandemic resulting from the COVID-19 outbreak devastated the way of life across the world. As of 31st of May 2021, 177 million individuals have reported contracting the virus worldwide while the death toll has reached 3.82 million, while 382,000 of these deaths are reported from India. Most countries turned towards 14-day shutdowns during the first wave of the pandemic to stop the spread of the disease. This resulted in an immediate halt in most production and manufacturing. Strict travel restrictions resulted in streets being practically empty in most countries. Though governments only introduced mandatory lockdowns in the latter part of March in 2020 in most South Asian countries, from February onwards a decrease in general activities was visible due to the initial measures. When the South Asian region is concerned, these restrictions were first imposed by Sri Lanka on the 20th of March 2020. This lasted till the 28th of June 2020 (Erandi *et al.*, 2020), India commenced its nationwide lockdown on 25th March 2020 and lasted till 03rd May 2020 while conditional lockdown was in place till 30th May 2020 (Sharma, S. *et al.*, 2020). Pakistan went into a nationwide lockdown from 1st April to 09th May 2020 (Mumtaz, 2020). while Bangladesh imposed strict restrictions on travel from 05th April to 28th April 2020. Nepal went through a cycle of nationwide lockdown from

24th March to 21st of July 2020 (Sharma, Banstola and Parajuli, 2020). For the study, the first 06 months of 2017, 2018, 2019 and 2020 are used.

Decrease in industrial and travelling related activities resulted in a phenomenal drop in all forms of pollution (Collivignarelli *et al.*, 2020; Menut *et al.*, 2020; Mousavinezhad, Lops and Seyadali, 2021). Resource consumption levels from the region indicate a steep decline in rates of resource utilization due to the limited activity during the period. Reports indicate that levels of air pollution and water pollution reached a recorded minimum during this period. Several articles suggest that the most decreased form of environmental pollution during this period is Air Pollution (Mousavinezhad *et al.*, 2021). Studies even indicate that the Ozone levels in the upper atmosphere have improved due to the temporary halt in anthropological emissions (Xing *et al.*, 2017; Sharma *et al.*, 2020). Decreased emissions have reduced the number of respiratory illnesses recorded during the period (Bourdrel *et al.*, 2021).

Since the South Asian region is prone to dangerous levels of air quality, reviewing the impact of COVID-19 lockdowns on air quality is a timely topic. This review focuses on variation in air quality during the lockdown, before and after, focusing on several key cities in the region. Unlike the East-south Asian region, South Asian countries have limited resources when air quality monitoring is concerned. India, being the largest economy in the region has already invested significantly in monitoring air pollution since 2017 due to the disturbing experience of high mortality rates due to air pollution (Vikas Singh *et al.*, 2020) . Sri Lanka only has 04 industry-grade operational automated air quality monitors in place. Another concern in studying Air Pollution trends is the outlying meteorological conditions over a period of time in focus. It is believed that the quality of air can drastically change due to severe and long-term meteorological events in the surrounding region (Micro, Meso and Synoptic scale)(Cheng *et al.*, 2017; Li *et al.*, 2019). Seasonal variation in air quality trends in most countries also associates with these seasonal meteorological changes. However, as for the previously conducted research on COVID-19 impact on air pollution over India, it is determined that the meteorological conditions during the large part of March and April seem to share the same meteorological characteristics over the four years from 2017 to 2020 (Vikas Singh *et al.*, 2020).

To perform time series analysis on air quality, the data sets used should be uniform, consistent, and reliable. However, except for the data sets from the Central Pollution Control Board of India, other countries lack consistent air pollution monitoring data required for the study. Lack of data is a common struggle faced in all air quality-related research. For the study, air pollution data is gathered through the Automated Air Quality Monitoring Stations located in the United States Embassy (airnow.gov, 2020) and Consulates in the region. The study primarily focuses on how PM2.5 concentration varied during the period of study.

II. METHODOLOGY

A. Analysis of overlaying Meteorological and Climatic Circumstances

Though the lockdown occurred generally in the same period over the south Asian region, the meteorological characteristics at the time vary drastically even within one country when analyzed closely. To overcome the difficulties of synchronizing the meteorological parameters is to use reference data from the same period for comparison. This will eliminate the impact of climatic conditions on air quality variation while significantly reducing the impact of seasonally driven meteorological parameters.

Even this method of analysis could be unfruitful if any major meteorological events had occurred during the overlaying period. Previous research suggests that the general meteorological parameters over the Indian subcontinent and the Bay of Bengal remained somewhat unchanged. This was confirmed through the analysis of MERRA-2 meteorological parameters from 2017 to 2020 as suggested by Vikas Singh *et al.* (2020).

B. Data Collection and Filtration

Availability and the method of collection of air quality data vary significantly due to different available technologies. Availability and non-availability of different parameters limit the scope of the study significantly. Kandari and Kumar (2021), Investigates variation of air quality over 08 south Asian countries using data from different sources including websites (aqicn.org; worldometers.info; iqair.com, etc.) and other sources like the World Health Organization, United Nations Environment Programme, National Aeronautics and Space Administration. This can create non-uniformity in the collected data. Manikanda et al., (2020) look decisively at air quality variation over more than 10 Indian cities concerning multiple parameters. Data uniformity is protected by utilizing data sets from uniform means of measurement. Central Pollution Control Board, India (CPCB) has provided data for the above study. However, the research compares overall yearly air quality trends from reference years 2017 to 2019 against 2020. Since the identified decrease in air quality only occurs in the lockdown periods, this approach can undermine the decrease in air quality significantly. Vikas Singh et al. (2020), used data from 134 different caliber measurement devices belonging to CPCB to analyze the decrease in air pollution over different regions of India due to the lockdown. This study aims to utilize a similar methodology to identify a decrease in air pollution. However, this research utilizes data sets from similar caliber measurement devices (Automated Air Quality Monitoring Stations) to increase the reliability of the comparison. Sharma, S. *et al.* (2020) also uses data from the countrywide CPCB air quality monitors to study several parameters while focusing on Air Quality Index (AQI) substantially. Sharma, S. *et al.* (2020) believes that AQI better reflects the change in air quality than any other individual parameter.

This study utilizes data from the network of Automated Air Quality Monitoring Stations maintained by the State Department of the United States of America. Data from the 2018 to 2020 period is used, primarily concentrating on the regional dominant pollutant, PM2.5. The granularity of the raw dataset is hourly averaged data points. In order to conduct a proper analysis, the raw data was cleaned and pre-processed to ensure quality and consistency. The data was observed to have outliers and Instrument codes for when the measuring device had been in calibrating stage or indicating errors. Since the dataset contains time series data, the error codes were not considered as invalid. Instead, data cleaning and transformation methods were applied to cleanse the corrupted data points. The timestamps with outliers were smoothed by using the quantile clipping method, which is an anomaly smoothing method that replaces the data points with values higher or lower than the 95th or 5th percentile respectively, with the percentile point value. The first step towards cleaning the instrumental codes was replacing them with missing values string (NaN) and next linear interpolation was applied to fill in the NaN. The pre-processing and analysis were all conducted using python libraries, mainly pandas, matplotlib and statsmodels. The cleansed data were finally resampled into daily averages and used for the analysis.

C. Time Series Analysis of the Air Quality

Cleaned and pre-processed data averaged per day is used to study the variation of air quality over the years. This initial analysis is done through a time series analysis in form of a graph. Selected 08 locations in 05 South Asian countries will be graphed for 2018, 2019 and 2020 separately. Macro analysis of the trend will be concluded by using combined 2018 to 2019 monthly data as reference and the data from 2020 as a comparison. Quantitative values of the variation are obtained through the following equation in terms of percentage. M_c refers to the 2020 data set while M_r refers to the reference data set. It is expected that the largest decrease in air pollution will occur overlaying the months of lockdown for each country.

$$Change\ in\ Air\ Pollution = \frac{M_c - M_r}{M_r} \times 100$$

III. RESULTS & DISCUSSION

A. Climate and Meteorological Circumstances

From literature review and data from the MERRA-2 platform indicates the variation in wind levels directions and precipitation levels over the Indian subcontinent and the Bay of Bengal remains stable throughout 2018 to 2020. No long-term or significant meteorological events were present during the period.

B. Data Collection

The study obtained hourly PM2.5 values from the Automated Air Quality Monitoring Stations, located in 08 locations over 05 countries in the South Asian Region.

C.Time Series Analysis

A clear decrease in recorded air pollution levels can be seen in the early half of the year 2020. It is already established that this occurred due to the lockdown which was enforced to stop the spread of the COVID-19 pandemic. In the case of some countries, the period in focus is recognized as the most concerning period when it comes to Air Quality.

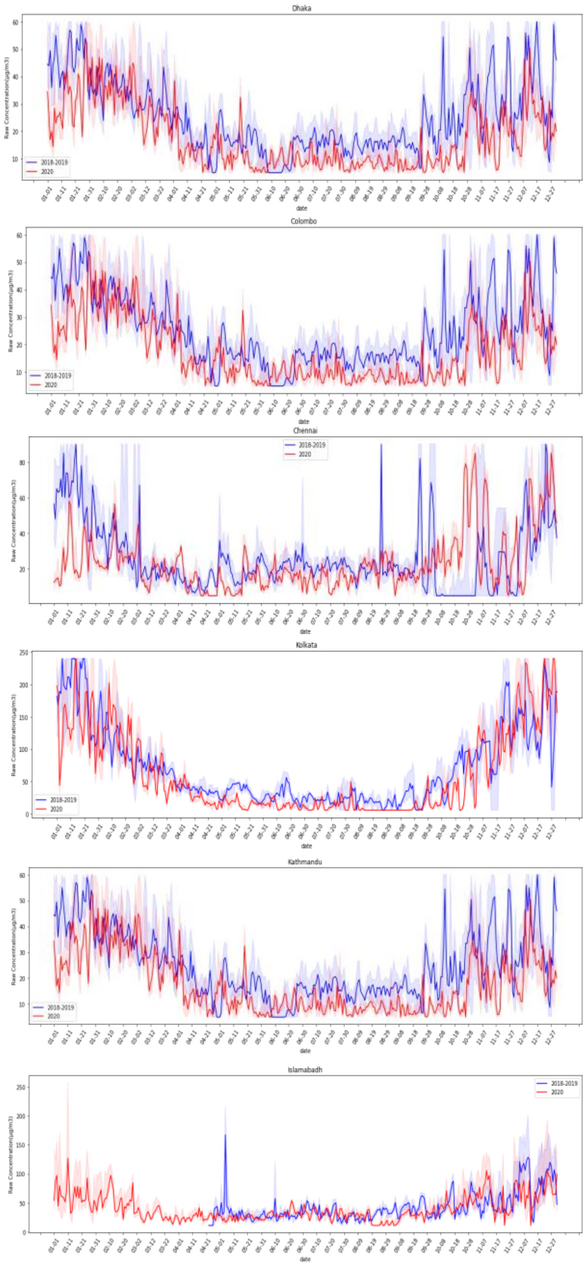

Figure 3. Behaviour of the daily median of reference years (2018 and 2019) and observed year (2020)

This enables the comparison to be more fruitful. In most cases, the lockdown was enforced for 30 days or similar. Hence, the box and whisker plots illustrate in Figure 1 the variation of Air Pollution over the first 06 months of the calendar year in each of the selected cities. It is observed that a decrease in pollution level and increase in air quality overlapping the period where the lockdowns were initiated is present. The most decreased pollution levels were recorded from the cities with a history of air pollution-related complications such as Delhi, Kolkata, Dhaka and Colombo. Figure 2 clearly illustrates the behavior of the daily median during the combined reference years and 2020. The reference years were grouped by month-day and the daily median was lotted in a clear single line plot while the interquartile range (Q_3 -Q_4) was plotted and filled in.

1) *Sri Lanka: City of Colombo*

Colombo is located on the west coast of Sri Lanka and is considered the financial hub of the country. It is identified that the dominant pollutant in the region is particulate matter (Seneviratne *et al.*, 2011). Premasiri *et al.* (2016) suggest that the visible pollution in the city is lower than the reality because most of the pollution is carried inwards through the strong coastal winds, away from the city. Previous research has also determined that the pollution landscape of the city is also affected by transboundary elements (Gunasekara and Waraketiya, 2020). According to the analysis results during the lockdown period, since the enforcement of the lockdown at end of March, 28.03% reduction in average monthly air pollution April, 30.3% reduction in May and 10.65% decrease in June is evident (Figure 03). The pollution trend in Colombo suggests that the city's highest pollution is recorded through the period of December to February. Slightly lower pollution is recorded from March to May.

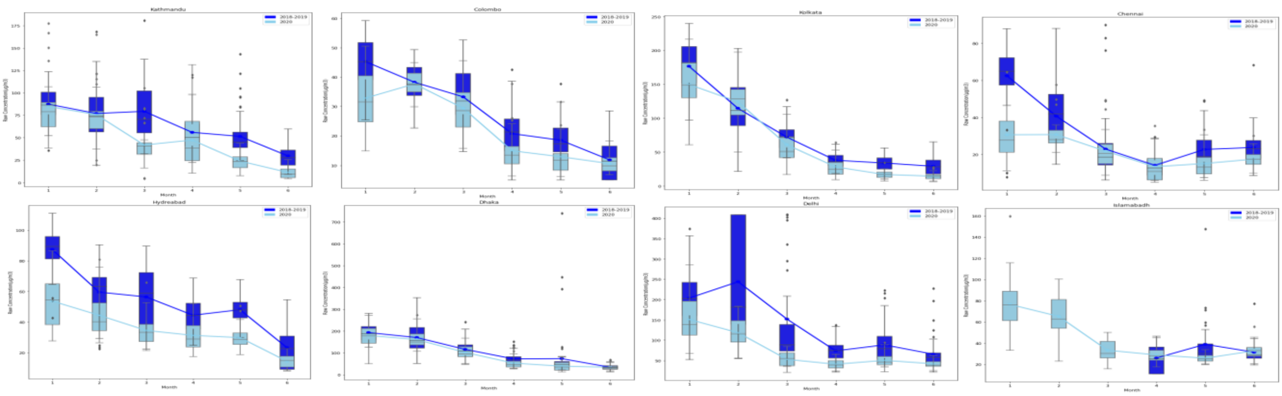

Figure 4. Box Plot Diagrams for Monthly Average

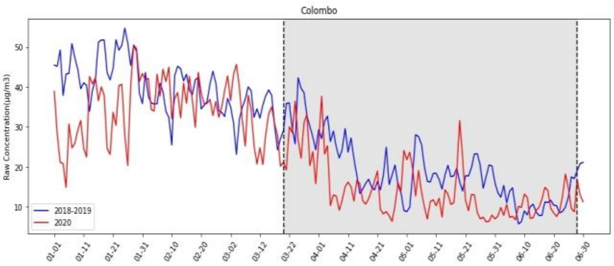

Figure 3: Air pollution variation in Colombo

2) India: Cities of Kolkata and Delhi

Both these cities are located in the northern part of India where the climate is dry, and the winds are moderate. As industrial cities with heavy population densities, Delhi and Kolkata are recognized as pollution hotspots of India (Gurjar, Ravindra and Nagpure, 2016). As per the air pollution trend observed in the reference years, the highest pollution in Delhi and Kolkata is recorded from November to January (Figure 04 and 05). Research links paddy field burning across the northern parts of India for this pattern (Gadde *et al.*, 2009; Lohan *et al.*, 2018). After the lockdown was enforced at end of March, the decrease in air pollution is staggering. The following table provides a quantitative decrease in air pollution compared with the mean of the reference years.

Table 1: Decrease in pollutant levels in Delhi and Kolkata.

Month	**Decrease in Delhi**	**Decrease in Kolkata**
April	25.69%	44.39%
May	49.98%	42.86%
June	50.39%	35.75%

3) India: Cities of Chennai and Hyderabad

These two cities are located in the southern part of India. Chennai is a coastal city while Hyderabad is not. Compared to the previous megacities, pollution levels in Chennai and Hyderabad is quite low (Manikanda *et al.*, 2020). These cities are known more as urban cities rather than industrial establishments. Chennai's pollution trends show peaks in November, December and January while Hyderabad's pollution trend is generally increasing from September and peaks in December January then decreases reaching the lowest in June to July (Figure 06 & 07). In general, the monthly average pollution levels in Hyderabad are higher than in Chennai. The monthly average pollution levels for the year 2020 are lower compared to the reference years. The following table provides a quantitative decrease in pollution levels for the two cities.

Table 2: Decrease in pollutant levels in Chennai and Hyderabad

Month	**Decrease in Hyderabad**	**Decrease in Chennai**
April	29.67%	5.08%
May	37.96%	33.57%
June	38.34%	26.53%

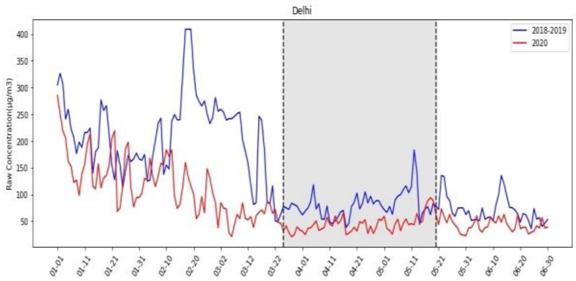

Figure 5: Air pollution variation in Delhi

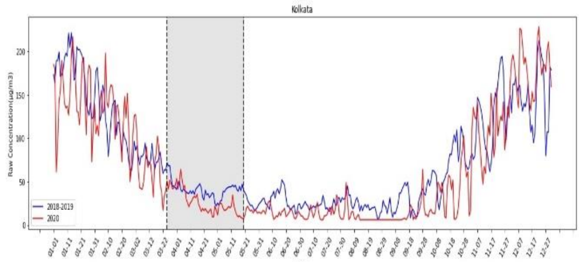

Figure 5: Air pollution variation in Kolkata

4. Bangladesh: City of Dhaka

Dhaka is the capital city of Bangladesh. As the mercantile hub of the country and the administrative capital, the population density in Dhaka is one of the highest in the world (Begum and Hopke, 2018). Pollution in Dhaka is identified to be caused by two major pollutants, PM2.5 and Lead (Begum, B.A., Hopke and Markwitz, 2013). According to previous research, the major source of pollution in Bangladesh is caused by the Brick Kilns and Vehicular Emissions (Begum, B.A. *et al.*, 2014). The pollution trend in Dhaka seems to be moderate throughout the year. Slightly elevated levels are recorded in the first 3 months of the year (Figure 08).

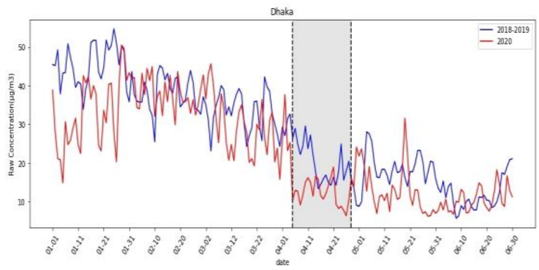

Figure 8: Air pollution variation in Dhaka

Strict lockdown in Bangladesh was only enforced from the first week of April to the last. Less than the other countries in the region. The decrease in pollution levels was also low compared to the regional average. The decrease in April was only 26.76%, Then the decrease increased to 47.32% in May then again returned to general pollution levels with only a reduction of 0.04% in June. Soon after the lockdown was over, pollution levels increased and reached those of the reference years.

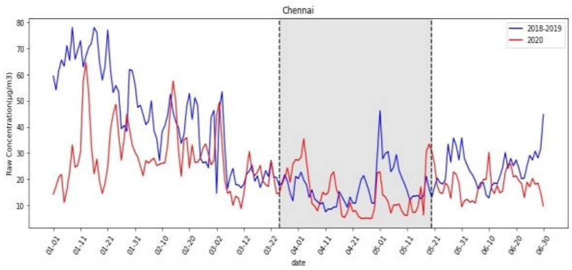

Figure 6: Air pollution variation in Chennai

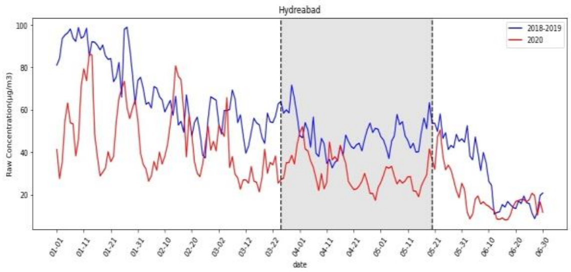

Figure 6: Air pollution variation in Hyderabad

5) Nepal: City of Kathmandu

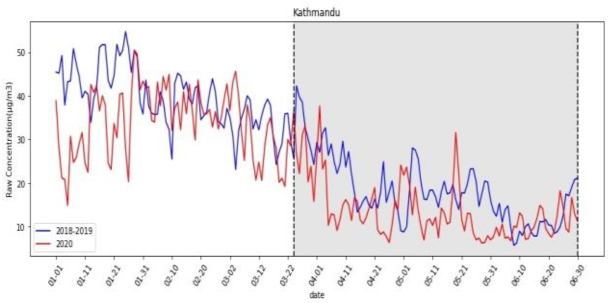

Figure 9: Air pollution variation in Kathmandu

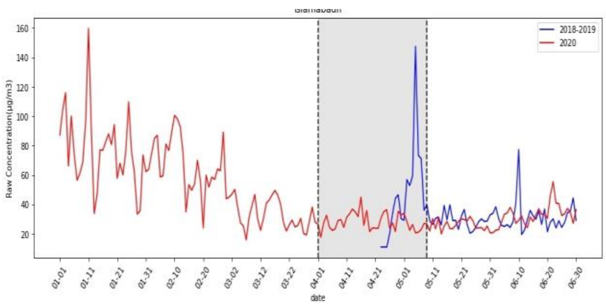

Figure 7: Air pollution variation in Islamabad

Nepal is landlocked by the two industrial giants in the region, India and China. The unique topography and meteorological characteristics of Kathmandu have uniquely contributed to the pollution levels in the city. The city of Kathmandu is located in the Kathmandu valley, surrounded by the Himalayan Mountain range. This bowl-like topography surrounding the city traps pollution in and decreases air quality further. Research has identified that the prominent pollutant in the region is again to be PM2.5 (Saud and Paudel, 2018).. Biomass burning and Vehicular emissions are found to be the major pollutant source in Nepal (Ramanathan *et al.*, 2010; Stone *et al.*, 2018). Researchers hint at the evidence of trans boundary pollution in the region but comprehensive research into pollutant dissemination is yet to be concluded (Aryala *et al.*, 2009; Bong Mann Kim *et al.*, 2015). Similar to Indian conditions, air pollution in Kathmandu increases in the latter part of the year which reaches its peak in December and slowly decreases (Figure 09). Nationwide lockdown in Nepal was enforced from the last week of March and extended till June. In April the monthly mean air pollution levels only decreased by 15.3% even though all activities in the valley were halted. Then the following month, air pollution dropped by a staggering 53.33% and again by 61.98% in June.

6) Pakistan: City of Islamabad

Climatic conditions in Pakistan are mostly dry. Pakistan is as intensely industrialized as India yet shows considerably high pollution concentrations in urban regions. Over the years pollution trend in Pakistan has slowly increased (Colbeck, Nasir and Ali, 2009). The major source of air pollution is identified as vehicular emissions and PM2.5 is the key pollutant. Other vehicular emission-related gaseous pollutants such as SO_2, NO_2 and Lead is also identified in large concentrations (Ghauri, Lodhi and Mansha, 2007; Ali and Athar, 2010). Studies concluded in Islamabad identifies as Afghanistan and Western India to be the source area through back-trajectory studies. Pollution concentration was highest at the city center, confirming that the major pollution source is vehicular emissions (Rasheed *et al.*, 2014). The lockdown period for Pakistan 1st of April and ended on the 9th of May. A much-relaxed restriction was in place afterward. No decrease in pollution levels was recorded in April (Figure 09). Following months recorded a decrease in monthly average pollution level by 33.77% which was then again increased in June when all imposed restrictions were removed. It is also essential to mention that only 2019 data starting from April was available for Islamabad to conduct the analysis.

IV. CONCLUSION

As expected, all the cities in the focus group recorded lower pollution levels and better air quality in 2020 compared to the two previous years. Trend analysis concludes that from the start of the year, recorded pollution levels were below what was expected. This could be motivated by the overall air quality improvement in the world. Most European countries and China imposed lockdowns before the threat was identified in the South Asian region. This observation can be evidence of long-range transboundary pollution, which is yet to be comprehensively studied in the South Asian region. European studies into Long-range Transboundary Pollution have proven that the upper atmosphere could transfer pollutants over incredibly long distances (Tørseth *et al.*, 2012).

Analysis of monthly average PM2.5 pollution levels provides us with evidence that the decrease in pollution levels over highly industrialized cities is higher than the others, except for Kathmandu and Dhaka. The lockdown period over Dhaka was only a month. Lowered pollution levels were only recorded the following month which again increased. Hence, the visible drop in pollution level is low. Though Dhaka is a heavily industrialized city, a short lockdown period resulted in only a slight decrease in pollution levels. Pollution in Kathmandu is found to be closely linked to vehicular emissions and biomass burning. However, the rate of decrease in pollution levels soon after the lockdown is lowest in the city of Kathmandu. This could be due to the topography of the city. Entrapped topography reduces ventilation and decreases the speed of pollutant removal. Coastal cities such as Colombo and Kolkata recorded a considerable improvement in air quality soon after the lockdown is enforced. These two observations provide clear evidence of how topography, location and climate influence the decrease in air pollution landscape over the study period.

In conclusion, the highest reduction in PM2.5 pollution levels in south Asia was recorded in Kathmandu during June 3 months after the lockdown was enforced and immediately before the lockdown was lifted the following month. The low rate of pollution decrease is associated directly with the topography and the location of the city. Chennai and Colombo are comparatively less industrialized in comparison to Delhi, Kolkata, or Dhaka. Pollution levels in these cities only slightly decreased which is less significant in comparison.

Most cities recorded the highest levels of PM2.5 pollutant decrease rates exactly about 30 days after the enforcement of the lockdown. This directs towards the assumption that generated pollution concentrations in urbanized cities tend to dissipate slowly. Environments with higher dispersion rates such as comparatively less urbanized coastal cities constantly recorded lower pollution values than inland cities, this is another observation that supports the above assumption. The trend of pollution decrease during the lockdown period suggests that optimum dissipation takes about 20 to 30 days in an urbanized city. Generally, for each city, the lowest pollution concentration was recorded 3 to 4 weeks after the lockdown was enforced. This is evidence that South Asian countries are suffering from passive air pollution and air pollution aggregation.

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