The impacts of COVID-19 on an Air Quality Metric ($PM_{2.5}$)

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ABSTRACT

On a worldwide scale, cities have experienced improvements in air quality levels since COVID-19 was declared a pandemic by the World Health Organization in March 2020. The result of the lockdown orders drastically changed people's lifestyles which resulted in reduction of particulate emissions in a number of cities globally. The aim of this paper is to do a qualitative analysis of correlations between emission levels of $PM_{2.5}$ after the start of lockdown in key cities around the world compared to their respective data of the previous year in 2019.

KEYWORDS
Air pollution, COVID-19, Particulate Matter ($PM_{2.5}$)

1 Introduction

Clean air is essential to maintain the general population's health. Currently, 91% of the world population lives in locations that exceed the World Health Organization (WHO) permissible limits [1]. More than 80% of citizens living in urban areas live in areas that exceed these limits, both indoor and outdoor.

While the overall impact of COVID-19 has been primarily negative in regards to total mortality and cases, it has had a profound positive impact on the environment. Recent anecdotal evidence has demonstrated that air pollution is reduced due to the lockdowns that countries have been enforcing. The most resounding evidence has been the ability to visualize the Himalayan mountain range for the first time in close to 30 years in the northern Indian state of Punjab [2].

In this paper, we will look into a particular air quality metric ($PM_{2.5}$) and how it impacts the general population. Additionally, we will discuss how countries monitor air quality and the global trends since the 1990s. Later, we will examine particular countries and how the COVID-19 pandemic has impacted the air quality due to societal changes.

2 Air Pollution Metrics

Air quality is rated on the Air Quality Index (AQI) based on differing levels of concern for the general public. The AQI ranges from Good to Hazardous based on five groupings of major pollutants [Figure 1]: Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter (2.5 and 10 µm in diameter) and Sulfur Dioxide (SO_2) [3]. While each of these air pollutants are important, our project and the remainder of this paper will focus on particulate matter. This is due to the fact that particulate matter has been found to impact the health of more people than any other pollutant [4].

AQI Category	AQI Value	24-hr Average $PM_{2.5}$ Concentration (µg/m³)
Good	0 - 50	0 - 15.4
Moderate	51 - 100	15.5 - 40.4
USG	101 - 150	40.5 - 65.4
Unhealthy	151 - 200	65.5 - 150.4
Very Unhealthy	201 - 300	150.5 - 250.4
Hazardous	301 - 500	250.5 - 500.4

Figure 1. AQI categories for $PM_{2.5}$ concentrations[5]

2.1 Particulate Matter

Particulate matter is made up of extremely small solid or liquid particles which can contain acids, organic compounds, metals and dust. Particulate matter is differentiated by the size of particle and classified as either particulate matter less than 10 µm in diameter (PM_{10}) or particulate matter less than 2.5 µm in diameter ($PM_{2.5}$) [6]. Typical particulate matter measurements are reported in terms of mean concentrations per cubic meter of air volume (µg/m^3).

Particulate matter is produced from a variety of sources. A portion of the particles are produced from simple sources such as agitation of terrain on construction sites and unpaved roads. In low and medium income countries, indoor particulate matter levels are especially high due to indoor fires for cooking, heating and lighting [7]. However, most particles are created via reactions in the atmosphere with chemicals or pollutants released from power plants, industrial operations or motorized vehicles [8].

WHO periodically releases air quality guidelines to help guide countries targets for overall air pollution. In these guidelines, the WHO published 3 intermediaries and a final PM target annual mean concentration to reduce public health risk [9]. These intermediaries are proposed incremental targets for areas with high pollution levels. These targets can be found in Figure 2.

WHOair quality guidelines and interim targets for particulate matter: annual mean concentrations[a]

	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Basis for the selected level
Iinterim target-1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to theIT-1 level.
Interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline (AQG)	**20**	**10**	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$

[a] The use of $PM_{2.5}$ guideline value is preferred.

Figure 2: WHO air quality guidelines and interim targets for particulate matter [9]

The health impact of these particles is severe, with the WHO estimating that particulate matter air pollution contributes to 800,000 deaths each year, which would rank as the 13th leading cause of mortality worldwide [10]. Inhalation of particulate matter is the most likely cause of negative health impacts. PM_{10} has been shown to be able to lodge itself deep inside lung tissue, while $PM_{2.5}$ can penetrate through lung tissue to enter the circulatory system and cause even more severe health impacts [7]. Chronic particulate matter exposure has been linked to the development of atherosclerosis via systemic inflammation [11]. Additional studies have shown with acute exposure to particulate matter, subjects have experienced changes in coagulation and platelet activation [12,13]. Using the American Cancer Society's Cancer Prevention 2 database, Pope et al. demonstrated that with each 10 $\mu g/m^3$ increase in $PM_{2.5}$ cardiopulmonary mortality rose by 9% (95% confidence interval (CI), 3-16%). Additionally, mortality secondary to arrhythmia, congestive heart failure and cardiac arrest rose by 13% (95% CI, 5-21%) and ischemic cardiovascular disease mortality rose by 18% (95% CI, 14-23%) for each 10 $\mu g/m^3$ increase in $PM_{2.5}$ [14,15].

3 Global levels of $PM_{2.5}$ before COVID-19 pandemic

3.1 Monitoring Status

The number of air quality monitoring stations greatly varies depending on the country and region. Currently the leaders in the quantity of ground based stations and monitoring networks are mainland China, Japan, and the United States [16]. The stations at these countries publish data in real-time, resulting in current and quality data that meets the criteria of being published in datasets and records. Many other countries and regions across the globe lack the adequate stations to produce real-time quality data on ground measurements of $PM_{2.5}$. To provide consistent data of global air pollution concentration, ground measurements are combined with observations from satellites and data from global chemical transport models [17]. Some error is expected due to the variance of equipment and facilities in monitoring sites across the globe and data should not be taken as absolute. Figure 3 illustrates the distribution of ground based monitoring stations across the world. The contrast between the availability of monitoring stations in developed countries compared to developing countries is evident.

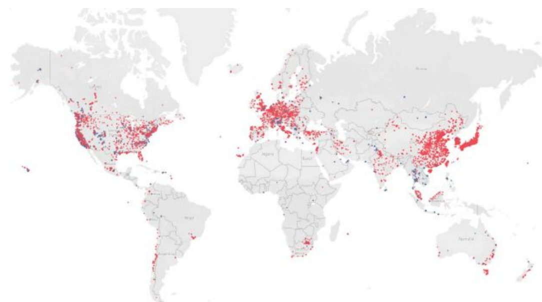

Figure 3: Density map of ground based air quality monitoring stations around the world [17]

3.2 Global levels of $PM_{2.5}$, 1990 - 2017

Globally, the levels of $PM_{2.5}$ continuously surpass the established target of 10 µg/m³ released by the World Health Organization. In 2017 the global average of $PM_{2.5}$ was 45.52 µg/m³, which can be seen in Figure 4. Although this number is well above the target level, approximately four times, the figure also illustrates how the levels of particulate matter has globally decreased since 2010. 2011 has so far been the peak of global $PM_{2.5}$ exposure at 50.77 µg/m³ with preceding years measured from 1990 to 2010 in 5 year increments are as follows; 44.26, 44.9, 45.94, 48.36, and, 50.25 µg/m³. The levels of $PM_{2.5}$ concentrations in 2017 are comparable to that of 2000 [18], indicating that in recent years there has been an effort to decrease $PM_{2.5}$ levels globally.

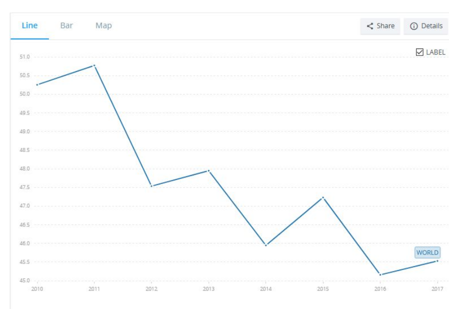

Figure 4: Global $PM_{2.5}$ average from 2010 -2017 [18]

4 Case Study Countries

In response to the COVID-19 pandemic, countries went into lockdown effectively shutting down many industrial activities globally. Transportation reduced dramatically due to restrictions and hesitancy by the general public. Air travel dropped by 96% due to COVID-19 to the lowest it has been in 75 years [19]. With 13,378,853 current cases and 580,045 deaths globally as of 07.16.2020, the public health impact of COVID-19 is profound, however this pandemic has also resulted in pollution reduction due to the social and economic restrictions that have been placed [20]. In this section, we will explore a select group of countries to establish their baseline air quality measurements and the implications of lockdowns on these measures.

4.1 China

4.1.1

In recent years China has been at the forefront of monitoring and reducing emissions, which has led to a significant decrease in their $PM_{2.5}$ emission rates, reflected by Figure 5 in 2017. Still China ranks as the 11th most polluted country out of 98 (that have sufficient data) countries in 2019 at 39.12 µg/m³, still continuing to make improvements (5%) from the previous year of 2018 at 41.17µg/m³ [21].
Beijing, China's capital alone has reduced their average $PM_{2.5}$ concentration levels by approximately 51% from 81.81µg/m³ to 42.1µg/m³. Wuhan also reflects this trend going from 51, 46.9, and 44.4 µg/m³ from 2017-2019 resulting in a 15% decrease in the course of 2 years. The median average annual $PM_{2.5}$ concentration levels for China is 33.5µg/m³ which is over the WHO standard by approximately three times [21]. Although China is making significant progress, 48 Chinese cities place among the top 100 for average annual $PM_{2.5}$ concentration levels [16].

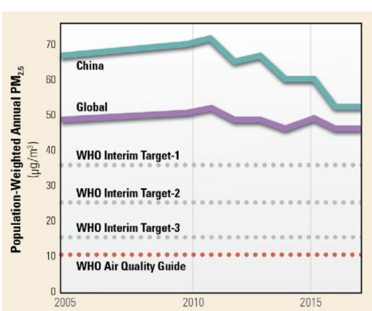

Figure 5: China and global $PM_{2.5}$ concentrations in comparison to WHO air quality targets [17]

4.1.2

The epicenter of the COVID-19 outbreak, Wuhan, and many other surrounding cities in China went into lockdown starting on January 23rd, 2020. The table shown in Figure 6 contrasts the monthly averages of $PM_{2.5}$ concentration levels in China between 2019 and 2020 during those months. The difference ranges from a maximum of 1.02% (January) to 18.87% (March). The low disparity between the values for January is likely due to the limited dates that are being accounted for. China's average monthly $PM_{2.5}$ concentration levels are overall lower for each month in 2020 than in 2019, indicating the potential of COVID-19 effect on China's air quality.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*
2019	*47.2*	*42.8*	*37.1*	*32.5*	*27.3*	*21.1*
2020	*45.6*	*35.4*	*30.1*	*31.5*	*24.4*	*18.2*

Figure 6: Average $PM_{2.5}$ (µg/m³) for China from Jan 23rd to June 30th

During the lockdown Wuhan experienced the lowest $PM_{2.5}$ levels on record for February and March at 36.8 µg/m³ and 32.9 µg/m³ in those months [16]. The prior year February recorded an average $PM_{2.5}$ level of 63.9 µg/m³ and in March 46.5 [21]. February saw a 48% decrease compared to 2019 and March saw a decrease of 29%. During the full lockdown period spanning 77 days from January 23rd to April 7th, Wuhan had an average $PM_{2.5}$ concentration of 35.4 µg/m³, which is down by 25% compared to the previous year's average of 44.4 [22].

4.2 India

4.2.1

India ranks as the 5th worst in terms of average annual $PM_{2.5}$ concentrations globally. 2018 had average rates of 72.54 µg/m³ and 2019 at 58.80 µg/m³. This significant reduction (19%) [21] aligns with the first launch of their National Clean Air Programme aimed to reduce particulate matter in 102 cities by 20% by the year 2024 [16]. Despite this improvement from 2018 to 2019 the average value of $PM_{2.5}$ is still similar to that of 2015 due to 2015 to 2017 seeing a significant increase in particulate matter.
In Delhi, the increase in levels from 2015 to 2016 was approximately 13% while the difference between 2015 and 2019 is approximately 3%. This indicates that between 2015 and 2018 there was a significant increase in emission levels in Delhi [21]. The average in 2019 in Delhi alone was at 98.6 µg/m³. Compared to the median of 48.8 using the average of Kota (49.1 µg/m³) and Kanpur (48.5 µg/m³), Delhi's average is twice as much in 2019 and almost ten times above the WHO standard [21].

4.2.2

Lockdown in India was mandated on March 25th and lasted until June 30th, being split into four different phases. The first phase started from March 25 and lasted over a three week period until April 14th [23]. During phase 1 of lockdown Delhi's $PM_{2.5}$ concentration levels were down by 60% compared to the same time in the previous year and down 55% from the average of the prior 4 years [22]. In 2020 Delhi experienced the best air quality ever recorded for March at 49.8µg/m³, which is a 33.86% decrease from the prior year's average in the same month and a 49.65% decrease from the annual average [21]. Mumbai also experienced the same effect from the lockdown and recorded 34.5µg/m³ in March. This value is 41.52% lower than the March average in 2019 and 23.84% lower than the annual average. During the three week period of the phase one lockdown, Mumbai's $PM_{2.5}$ level was down 34% compared to the annual average of 2019 and 43% from the average of the past four years [22]. During lock down these two cities have seen a significant decrease in particulate matter levels, with Mumbai going under the target concentration level of interim target-1.

4.3 United States

4.3.1

Due to the Clean Air Act established in the 70's the United States has one of the world's most established air quality monitoring networks [16]. The United States ranks as the 87th most polluted (i.e. 12th least) out of 98 in regards to $PM_{2.5}$ levels [21], reflecting their efforts established by the Clean Air Act. Their average $PM_{2.5}$ concentration levels for 2018 was 9.05 µg/m³ and 2019 was 9.04 µg/m³. Their improvement from these years is only .1%, but the US is one of the 18 (recorded) countries whose average is below the WHO standard.

Despite having an exceptional average some cities in the US are not without their problems. 20.9% of US cities still exceed the WHO annual average [16]. On average cities in the midwest such as Chicago and Indianapolis have seen an increase in their annual average from 2018 to 2019. Chicago going from 10 µg/m³ to 12.8 µg/m³ (21%) and Indianapolis increasing from 9.4 µg/m³ to 12.7 µg/m³ (26%). Comparatively Los Angeles, which resides in a state that suffers from wildfires has seen a decrease in their $PM_{2.5}$ concentration levels by 13% from 14.4 µg/m³ to 12.7 µg/m³ from 2018 to 2019 [16]. Although progress is being made Los Angeles is still above the WHO standard. Unlike LA or Chicago, some major cities like New York (7.0 $PM_{2.5}$) and San Francisco (7.1 $PM_{2.5}$) have their averages below the standard and also the US's median, Naples, NY at 7.7 $PM_{2.5}$ in 2019 [21].

4.3.2

The US has had varying responses to the pandemic and has mandated lockdowns on a state by state basis. The states to respond the earliest stated in the span of March 19th to the 24th, with California starting the earliest on 19th and New York following on the 22nd. During the three week span of March 23rd to April 13th Los Angeles recorded an average 5.6 µg/m³ $PM_{2.5}$ concentration, a decrease of 27% compared to the same month of the prior year and 56% decrease from the annual average, resulting in the cleanest recorded air quality for the city. New York in the three week span recorded an average of 4.4µg/m³, down by approximately 38% from the March 2019's average (7.1µg/m³) and the annual average (7.0µg/m³) [16]. Chicago recorded a PM2.5 concentration level of approximately 12.1 µg/m³in March [24], resulting in a 16% decrease from the prior years average of 14.4 µg/m³ of the same month [14]. In April Chicago only saw a decrease of 9% from 2019 to 2020 [24]. During the 3 week span mentioned above, Chicago recorded a value of 12.5 µg/m³, resulting in a value relatively close to the annual average of 2019 (12.8 µg/m³).

4.4 Europe

In 2019, only 36% of cities in Europe were under the WHO $PM_{2.5}$ target concentration [16]. $PM_{2.5}$ concentrations were found to be the highest in Eastern and Southern Europe, while the cleanest areas were in Northern and Western Europe. In addition to containing lower concentrations of $PM_{2.5}$, the Northern and Western regions have more dense air pollution monitoring coverage. In the following two sections, we will take a closer look at two of the earliest countries to be impacted by the COVID-19 pandemic in Europe.

4.4.1 Italy

While many countries in Europe have fully dedicated governmental air quality monitoring stations to provide their citizens with real time data, Italy's government does not have a comprehensive enough network to report these findings in real time. In addition to the governmental environmental monitoring equipment, private entities supplement the air quality monitoring to provide 100% coverage of the country in real time [16].

There are an estimated 84,400 premature deaths due to $PM_{2.5}$ in Italy. Italy is the 12th most polluted country in Europe [16]. In 2019, Ceglie Messapica, Italy was the 14th most polluted city in Europe with an average $PM_{2.5}$ concentration of 30.7 µg/m³ [16].

Italy was the first European country to announce official lockdowns due to the pandemic. First, northern Italy announced a lockdown on March 10th, followed by a nationwide announcement two days later on March 12th. While non-essential movement declined, during the three week period of March 23 - April 13, $PM_{2.5}$ levels collected in Rome rose by 30% in comparison to the previous year [16]. This is likely due to the increased reliance on domestic heating, which has already been found to be a significant source of air pollution from November 1 to April 15 [25].

4.5.1 Spain

Out of the 37 countries reported, in 2019, Spain had the 28th highest concentration of $PM_{2.5}$. In previous years, Spain has used the Air Pollution Risk Assessment System to conduct research regarding air pollution and its impact on public health. This project was able to model multiple different scenarios from 2004-2011 to model the potential $PM_{2.5}$ emission levels dependent on potential reductions in $PM_{2.5}$ precursor emissions [26]. Using these models, they were able to propose a scenario to reduce overall $PM_{2.5}$ levels by up to 4μg/m^3 [26] which would reduce the number of avoidable deaths secondary to $PM_{2.5}$ inhalation.

In Spain, the first confirmed case of COVID-19 was identified in February 2020 [27]. Following Italy, Spain was the second European country to announce a non-essential movement lockdown on March 14th. Due to this lockdown, nationwide $PM_{2.5}$ levels from the three week period of March 23 - April 13 dropped 11% from the previous year. Interestingly, even with this 11% decrease from the previous year, comparing the $PM_{2.5}$ data to the previous four years does not show a clear downward trend similar to just the previous year. Two weeks after the lockdown began, Barcelona weather stations measured a PM_{10} decrease by approximately 30%. Due to this decrease, Barcelona has not exceeded the WHO air quality guideline targets in particulate matter since early March [28]. As data is released in more cities, additional analysis will need to be done to clarify the longer term implications of the lockdown on air quality measures [16].

5 Conclusion

The effect of restricted human activities due to the COVID-19 pandemic across the globe from March 23rd of 2020 to April 13th of 2020 to the levels of $PM_{2.5}$ concentrations in China, India, US, Italy, and Spain resulted in overall decrease in these countries and their key cities. Countries with high average values of $PM_{2.5}$ concentrations in prior years, such as China and India saw a more significant decrease in their concentration levels compared to their counterparts who had much lower average values. In countries and cities we explored in this paper with lower average $PM_{2.5}$ concentrations most fell under the WHO standard of 10 µg/m³. There were exceptions to this rule such as Chicago in the US and Rome in Italy. Although seeing a decrease in their average $PM_{2.5}$ concentration levels in March and April, the differences were insignificant and the average recorded during the three week span was akin to monthly concentration values in 2019. Rome on the other hand had an increase in their concentration levels compared to 2019's average, being the only city that we researched with a negative impact to air quality due to the lockdown. Extrapolating from this research, it is likely that most countries and cities around the world experienced decrease in average $PM_{2.5}$ concentration levels, with exception of some outliers like Rome and would like to explore this topic further with our implementation project.

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