

Air Pollution and Control
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Lecture 52

Impact of Lockdown on Air Quality


Hello, friends. Today we will discuss about impact of lockdown on air quality, because this is a unique opportunity because of COVID-19, several countries had lockdown and that lockdown, stopped all kinds of energy related emissions or transport related emissions or industrial emissions.


So, this is a unique opportunity to see whether some air quality improvements were there, some special decrease or increase trend were there, because emissions come from natural sources as well as manmade sources. So, manmade sources were greatly affected by the lockdown. So, this is a unique opportunity for atmospheric scientists, for environmental engineers to look into the trends of the air quality in urban areas as well as at the regional scale.

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So, we will look into the effect of lockdown on air quality in different countries and regions, like, Sao Paulo in Brazil, we have gathered some data basically. So, this is a kind of indicative or illustrative presentation and taking some inspiration from this, you can further review some literature and you can get more insight basically.

So, we will include the Sao Paulo, Brazil, then Northern China related data, European data we have, then this Italy, Lombardi, Barcelona, Spain, USA, India, and we will try to learn some lessons from these studies that can we relate those emissions and air quality with respect to

some sources, because basically, it will give us an indication that which source is more important.

Air pollution comes from various sources and air pollutants have characteristics like transport has CO emissions or NO_x emissions in large quantity. Power plants, coal-based power plants, they emit lot of particulate matter and SO₂, so, that way some signatory pollutants we can try to relate.

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The slide is titled "Introduction" and contains three bullet points. To the right of the text is a green icon of a virus with a padlock in the center, with the text "LOCKDOWN Covid-19" below it. At the bottom right of the slide is a small video thumbnail showing a man speaking. The source is cited as <https://www.who.int/>. The slide footer includes logos for "Swayam" and "SWAYAM" and the number "3".

Introduction

- COVID-19 pandemic is one of the biggest global public health emergencies in recent centuries.
- The threat of COVID-19 spread caused global health emergencies, resulting in government's unprecedented decisions, including the lockdown of cities, specific states, or whole countries.
- The lockdown has led to massive economic loss to the world; however, it has come as a relief to the environment.

Source: <https://www.who.int/>

LOCKDOWN
Covid-19

3

So, you remember this COVID-19 pandemic, this is one of the biggest global public health emergencies in recent centuries as we know in our memory. And the threat of this COVID-19 is spread caused various governments to do lockdown in cities as well as in entire countries sometimes they did for certain period.

So, this particular phenomena led to massive economic losses of course, but sometimes we say that human beings are so creative, they try to look into some positive aspects or positive side of any tragedy or whatever happens. So, this was a kind of relief in terms of the impact to the environment. People first time saw blue skies, very clean air and many ecosystems got rejuvenated, there were some evidences of that nature.

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Effects of lockdown on Air Quality

- During lockdown, the **restricted vehicle movement, closure of industries and other activities** resulted in a significant reduction in anthropogenic emissions of air pollutants.
- This led to an **improvement in the air quality of many cities worldwide**, which was far possible to achieve despite several measures.

Source: <https://www.who.int/>, Girdhar et al., 2021



The slide features three rows of 'Before' and 'After' photographs. The first row is for New York City, showing a hazy skyline before and a clear skyline after. The second row is for New Delhi, India, showing a hazy street scene before and a clear street scene after. The third row is for Barcelona, Spain, showing a hazy cityscape before and a clear cityscape after. A small video inset in the bottom right shows a man in a suit speaking. The slide also includes a source link and logos for WHO and Swachh Bharat Mission.

So, during lockdown these visual effects basically, like, because vehicles movements were restricted, industrial production was not there, then other activities were also completely stopped. So, the emissions which were related to those activities went or vanished, or went out.



And this visual impact like, before this New York City before the lockdown this was the kind of picture, after this was so much clearer, before this Barcelona before the lockdown was this kind of hazy picture, and then it was very clear. Similarly, New Delhi this before and after. So, those pictures reveal their, story or tells their story that how this emission related air quality and the poor air quality can be addressed by if we reduce the emissions from various sources.

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Effects of lockdown on Air Quality: Sao Paulo, Brazil

Sao Paulo, Brazil

- In late March 2020, partial lockdown was ordered by the Sao Paulo state government.
- Data was analysed from four air quality stations in Sao Paulo, Brazil to assess air pollutant concentration variations during the partial lockdown
 - Urban Road I: Marginal Tiete, ✓
 - Urban Road II: Marginal Pinheiros, ✓
 - City center, and
 - one air quality station (Industrial) in Cubatao



Source: Nakada and Urban, 2020

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Now, we will try to relate which kind of air pollutants were reduced significantly, and which polluters did not have much effect on that. Now, like one example is Sao Paulo of Brazil. So, there were these four air quality stations where air quality data were borrowed, and these were like urban roads in this particular Sao Paulo, this crosses the Sao Paulo, another road is there, then city center data and then another city industrial location of Cubatao. So, within Sao Paulo state, these Sao Paulo city as well as a nearby city but Sao Paulo is also a state basically, in Brazil, this is the name of the state as well as the city.

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Effects of lockdown on Air Quality: Sao Paulo, Brazil

Sao Paulo, Brazil

- For each station, daily data (24 h) from February, March and April of the years 2015 to 2019 were used to calculate the mean levels of each pollutant for each month, and therefore estimate a five-year monthly trend.
- Similarly, data from February 25, 2020 to March 23, 2020 (four-week before partial lockdown) and from March 24, 2020 to April 20, 2020 (four-week during partial lock down) were used to calculate the mean levels of each pollutant both before and during the partial lockdown.



Source: Nakada and Urban, 2020

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Now, for each station what kind of data they obtain daily data 24 hours from February, March and April for the year of 2015 to 2019. So, 5 years data was taken for these three months,

February, March and April. And these were the months for this lockdown, in between some months were there, some days were there. So, comparison was made.

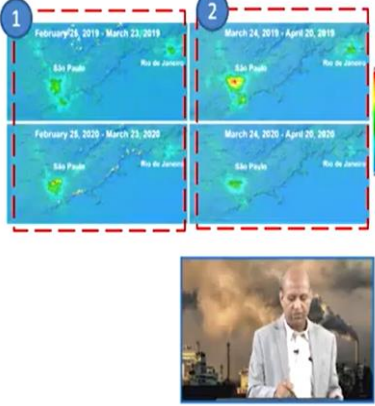
Similarly, like February 25, 2020 to March 23, 2020, so four weeks before partial lockdown this data was obtained, and then from March 24, 2020 to April 20, four weeks during the partial lockdown. So, those data were available so that comparison could be established.

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Effects of lockdown on Air Quality: Sao Paulo, Brazil

Sao Paulo, Brazil

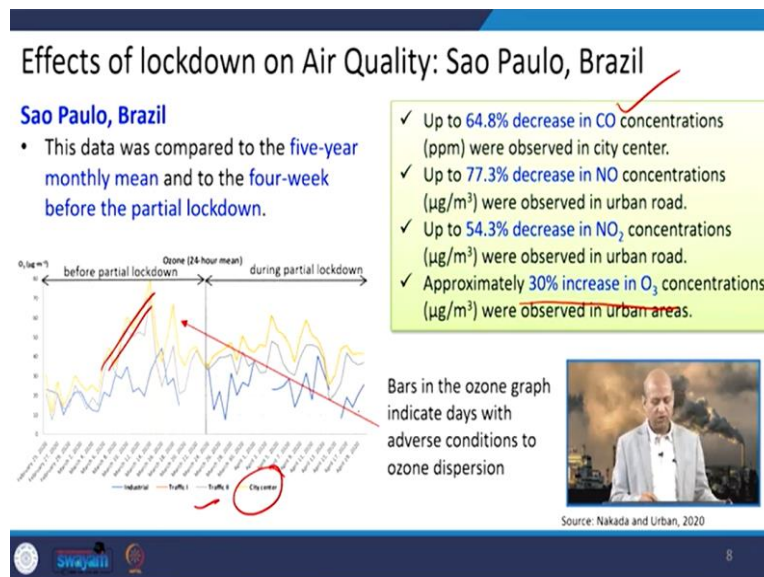
- The NO_2 concentration reductions can be visualized by satellite measurements of background tropospheric NO_2 concentrations.
- The NO_2 levels over the Metropolitan Area of Sao Paulo (2100 km^2) decreased during the partial lockdown :
 1. - 27% compared to the four-week before the partial lockdown (February 25, 2020 to March 23, 2020) in Sao Paulo
 2. - 45% compared to the same period (March 24, 2020 to April 20, 2020) in 2019.



Source: Nakada and Urban, 2020

Now, NO_2 concentrations reductions were observed. And 27 percent, this comparison with the four week before the partial lockdown and 45 percent, if we look into the observatory data, observation made during the partial lockdown. So, those background tropospheric NO_2 concentrations were made available.

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So, effect of lockdown in various ways you can interpret like, there are reduction, significant reduction in CO concentrations, carbon monoxide like 64 percent, NO concentration 77 percent reduction is observed, NO_2 around 54 percent, but ozone, there is no decrease in ozone rather it is increase. And ozone as you know, this is not primary pollutant, but secondary pollutant which is produced due to photochemical reactions in the presence of its precursors like NO_x , CO, hydrocarbons, VOCs etc.

So, in this before partial lockdown there is increased, but very interesting phenomena you can look here like industrial site were observed, when there is some decrease in the ozone and there is increase in the ozone at some sites of like traffic one and city center. And then in during partial lockdown there was not so much increase, but overall increase was observed in the ozone concentration and why this was the increase trend in the ozone that is something to look into.


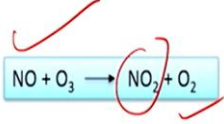
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Effects of lockdown on Air Quality: Sao Paulo, Brazil

Sao Paulo, Brazil

- In Sao Paulo – SP, road traffic accounts for approximately 68% of NO_x and 98% of CO emissions.
- One recent research has demonstrated that traffic emissions from heavy-duty diesel trucks are major sources of NO.
- By contrast, an increase in ozone concentrations in urban areas highly influenced by vehicle traffic was observed.
- Ozone concentration increases have been associated with the decrease of NO, which may cause a decrease in ozone consumption, thus leading to a higher ozone concentration.

Source: Nakada and Urban, 2020



So, basically there are various theories as you know, these precursors if available, only then ozone is produced. So, if precursors are not there, like NO_x emissions have been reduced drastically, and especially this titration phenomena happens when lot of NO is emitted by transport sector, if ozone is produced, then it reacts with the NO and it produces NO₂ and then oxygen.

So, ozone is reduced by this reaction NO. So, if NO is not there, then ozone concentration will increase, because there is no NO to consume ozone and like in city centers, you will not find much ozone, but in countryside you will find much ozone in comparison to the city center and this is the reason.

Because, in city center these emissions of NO is much more due to vehicle activities and that NO consumes ozone and NO₂ is produced which goes into the downwind direction of the cities and when they find lot of sunshine and that NO₂ again take part into production of the ozone that cyclic reaction of ozone production.

Well, so, these are the issues that if NO_x is not there, NO is not there to consume the ozone then ozone can increase because there is no this titration reaction. Another story, another theory is that this ozone production is related to whether NO_x driven or VOC driven or NO_x limited or VOC limited.

So, at some places it is NO_x limited, then if you reduce the NO_x then maybe ozone reduction will be there, if it is VOC limited and you reduce the NO_x then ozone will not decrease rather it will increase because you are not targeting the VOCs. So, that is phenomena also that if

VOCs, hydrocarbons are not addressed and they are being emitted by several sources, ozone increase maybe observed. So, several assumptions are there.

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Effects of lockdown on Air Quality: Northern China

Northern China

- Daily air pollution data including air quality index [AQI], SO₂, PM_{2.5}, PM₁₀, NO₂, and CO, daily weather data, real-time human mobility data, and lockdown time lines of 44 cities in north China from a span of 1 January and 21 March 2020 (covered 81 days) were analyzed to estimate the effects of travel restrictions on air pollutants concentration.



Source: Zhang and Bao 2020

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Here we are just looking into data with the simplified observations and analysis. If you want to go into detail then better you go through those papers and try to find out what are the exact regions. We are here just trying to link the possibilities.

So, in Northern China, this is another observation, Northern China, this lockdown effect was there. And it was observed that impact on AQI, Air Quality Index or sulphur dioxide, then PM_{2.5}, PM₁₀, NO₂, and CO, daily weather data, real time human mobility data, all these data were gathered for 44 cities and for the span of period of 1st January to 21st March 2020 it covered 81 days.


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Effects of lockdown on Air Quality: Northern China

Northern China

- Human mobility **dropped** by 69.85% after governments implemented travel bans
- The air quality index (AQI) **decreased** by 7.80 %
- Reduction/decrease was observed in five air pollutants, i.e., SO₂ (6.76%), PM_{2.5} (5.93%), PM₁₀ (13.66%), NO₂ (24.67%), and CO (4.58%).

Source: Zhang and Bao 2020



Legend: aqi

-18.61 - -39.76
-39.76 - -29.42
-29.42 - -22.27
-22.27 - -4.20
-4.20 - 22.91

AAQI [Before lockdown - After lockdown]

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And then there was this drop in human activities or mobility related activities around 70 percent and that resulted into AQI decrease around 7.80 percent, and reduction in concentration of SO₂ like around 7 percent, PM_{2.5} around 6 percent, PM₁₀ around 14 percent and NO₂ around 25 percent and CO around 5 percent. So, because their sources are different and different activities are there, that is why non-uniformity of reduction is observed basically.


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Effects of lockdown on Air Quality: Northern China

Northern China

- The results suggest that the **implementation of travel restrictions** dramatically reduced air pollution in 44 cities in northern China.
- However, the reduction ratio largely varied among the different air pollutants. Among them, **PM₁₀ and NO₂ showed a higher reduction ratio.**
- NO₂ and PM₁₀ resulted primarily from **vehicle exhaust and road dust generated by transportation.**

Source: Zhang and Bao 2020



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So, the results suggest that implementation of those travel restrictions have resulted in reduction of NO_x emissions or CO emissions even fine particles like PM_{2.5} and PM₁₀.

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Effects of lockdown on Air Quality: Europe

Europe

- The impact of the control measures during the COVID-19 lockdown in Europe (15 March–30 April 2020) on 1-h daily maximum nitrogen dioxide (NO_2) and maximum daily 8-h running average ozone (O_3) observations obtained from the European Environment Agency's air quality database (AirBase)



Source: Herrera et al., 2020

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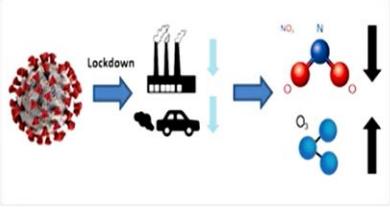
If we talk about the Europe, then the impact of these control measures for the COVID-19 from 15th March to 30th April, for one-hour daily data of nitrogen dioxide and ozone these two data were observed to see what was the impact on the air quality.

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Effects of lockdown on Air Quality: Europe

Europe

- Over the whole continent, the NO_2 concentration **decreased** consistently. The reductions range from 5% to 55% compared to the same period in 2015–2019 for 80% of the sites considered.
- O_3 concentrations showed a different pattern, decreasing over Iberia and **increasing** elsewhere.



Source: Herrera et al., 2020

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So, in Europe basically, if you look into this entire region of several sites, it was observed that NO_2 concentration decreased in a big range like 5 percent to 55 percent in 80 percent of the sites of the observations. But in case of ozone basically, there was at a particular site of this Iberia, the decreasing trend was observed otherwise, in entire Europe increasing trend was observed for ozone as it was observed in like Brazil or elsewhere.

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Effects of lockdown on Air Quality: Europe

Europe

- The **low NO₂ concentrations** are mostly attributed to the emission reductions.
- The **stable weather conditions**, with reduced ventilation and precipitation over large parts of Europe, **could not offset the emission reductions**.
- The **meteorologically adjusted NO₂ decreases** are larger than observed due to these meteorological conditions, especially in central and Eastern Europe.



Source: Herrera et al., 2020

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So, this is something which we have to look into, like there was a concentration of NO₂ decrease was there, but decrease, maybe, somewhere less, the reason could be like a stable weather, if that stable weather was not there, if we do not account for those metrological factors, then the decrease could be much higher, but it is still, there is a good range 5 percent to 55 percent at different locations.

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Effects of lockdown on Air Quality: Europe

Europe

- **Meteorological effects contributed to lowering O₃** concentrations in Iberia and raising them in the rest of Europe, explaining a large proportion of the observed changes.
- The main **meteorological variables** driving the ozone anomalies vary with the **geographical location**. They were dominated by
 - Elevated **temperatures** in the British Isles, France, Benelux and Germany
 - Low specific **humidity** in Eastern Europe
 - Elevated **solar radiation** around northern Italy and Austria
 - Low solar radiation, high specific humidity and reduced zonal wind in the Iberian Peninsula



Source: Herrera et al., 2020

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But at a particular site of Iberia, this ozone decreasing was observed and that was because of some metrological effects, because it is a photochemical reaction it needs not only the precursors, but also the sun shine and those kinds of issues are there. So, because of this

meteorological variables, there is variation in trend of the ozone whether it is decreasing or increasing like humidity temperature, solar radiation, all these play a role.

But, entire Europe except this Iberia the increasing trend was observed that was quite natural, because NO_x is not there that is the precursor or maybe VOC related limitation, limited the kind of phenomena may also be the reason.

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Effects of lockdown on Air Quality: Lombardy, Italy

Lombardy, Italy

- Due to the rapid rise of infections, on the 23rd February 2020, a new ordinance from the authorities resulted in the closure of all schools and placed restrictions on social and economic activities throughout the Lombardy region.
- On the 8th March 2020, the Government declared a **partial lockdown (PL)** and on the 23rd March 2020, a **total lockdown (TL)** was imposed and only factories attributable to essential supply chains (e.g. food, pharmaceuticals, etc.) were operative.



Source: Minno et al., 2020



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If you look into this Lombardy of the Italy, due to this rapid rise of infections, there from 23rd February, 2020 new ordinance was passed for the closure of all schools and other restrictions were applied basically in that region. And on 8th March 2020, the government declared a partial lockdown and 23rd March onward, it was a total lockdown.

So, this all like factories or industries were closed except, some important like food related those kinds of supply chains. So, those were kept free otherwise, total lockdown was there. So, this again resulted into emissions reduction, because sources are not there.

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Effects of lockdown on Air Quality: Lombardy, Italy

Lombardy, Italy

- The trends of 9 pollutants in meteorologically comparable periods were studied.
- Lockdown determined a significant reduction of PM_{10} , $PM_{2.5}$, BC, benzene, CO and NO_x .
- SO_2 remained unchanged in the more peripheral areas, while decreased in Milan.
- Part of the ozone increase was probably due to the lower NO measured during lockdown



Source: Minno et al., 2020

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So, the trends of the 9 pollutants were observed during this lockdown period that is PM_{10} , $PM_{2.5}$, black carbon, benzene, carbon monoxide or NO_x emissions. And it was found that SO_2 there was not big change, SO_2 remained unchanged in this peripheral area. So, that was maybe like residential related activities or coal burning related activities. The part of ozone increase was probably because of lower of NO that we have tried to establish in previous slide also.

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Effects of lockdown on Air Quality: Lombardy, Italy

Lombardy, Italy

- CO reduction is combination of causes:
 - (i) decrease in vehicular traffic and
 - (ii) reduction in the use of household heating due to the closure of many workplaces for the total lockdown
- The emissions of power plants, heating systems, and some industrial processes represent the main sources of SO_2
- This SO_2 reduction in Milan can be partially attributed to the decrease of heating, due to the closure of workplaces, factor playing a minor role in other areas.



Source: Minno et al., 2020

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Then if we look into the CO reduction, so, that was because of this traffic, vehicular traffic reduction was there and CO comes in large quantity from vehicular emissions, the emission of power plants, heating systems are main sources of the SO_2 . So, this SO_2 reduction in Milan can be partially attributed to the decrease in heating related activities.


Because, workplaces are closed, there are no people to go factory, those they are also closed, so, those offices which were requiring this heating, so, that requirement is not there. So, in that sense the heating requirement was lessened, so, reduced. So, SO₂ reduction was also observed.

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Effects of lockdown on Air Quality: Lombardy, Italy

Lombardy, Italy

- The significant lowering of the NO concentration which, in turns, reacts with O₃, could lead to obtain the higher O₃ concentrations than the average.
- The more accentuated increase in Milan was, probably, due to the higher average concentrations of benzene in Milan than the adjacent areas that may have promoted the formation of O₃ in a more significant way.
- VOCs, including benzene, are mainly produced by vehicular traffic and other incomplete combustion processes that PL and TL have increasingly limited.



Source: Minno et al., 2020

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Well, if we talk about this ozone, so, the significant lowering of this NO concentration which consumes ozone due to titration kind of reaction so, this low NO resulted into increase in the ozone concentration because there is no NO to consume ozone and ozone buildup was there because other factors were available to produce the ozone.

So, higher average concentrations of this benzene was also observed in Milan. So, these VOC limited in environment or VOC driven environment, ozone may increase, because then NO_x related titration may not play a role in producing or decreasing ozone. So, VOCs including benzene they are mainly produced by though vehicular traffic, but incomplete combustion processes and other they also play a role, but they come from other areas or other activities also.

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Effects of lockdown on Air Quality: Barcelona, Spain

Barcelona, Spain

- Lockdown measures came into force in Spain from March 14th, two weeks after the start of the SARS-CoV-2 epidemic, to reduce the epidemic curve.
- Since March 14th, lockdown measures were in place in Spain, restricting social contact, reducing public transport, and closing businesses.
- Data have been collected from February 16th to March 30th, 2020 on PM₁₀, NO₂, SO₂, and O₃ for the city of Barcelona.



Source: Querol et al., 2020

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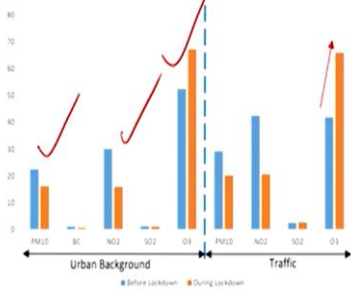
In Barcelona, Spain, then another study was observed. So, lockdown was there from March 14th and like restricting social contact or these reducing public transport or closing businesses, so, the data were available from 16th March to 30th March 2020 for PM₁₀, NO₂, SO₂, and ozone for this city of Barcelona.

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Effects of lockdown on Air Quality: Barcelona, Spain

Barcelona, Spain

- NO₂ and BC concentrations were reduced by half during the lockdown (more windy and wet) period.
- PM₁₀ decreased but in a much lower proportion, causes for the lower abatement are still unknown.
- O₃ concentrations increased before and during lockdown.



Source: Querol et al., 2020

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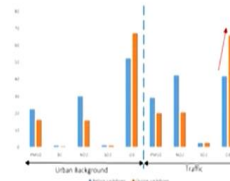
And there is a reduction in PM₁₀ or NO₂, SO₂ and BC there is because emissions are less. So, that significant decrease not observed, but in case of PM₁₀ and NO₂ is visible. In case of ozone, it is, like whether it is urban background or the traffic related background, it is increase is there, ozone production the same trend, because NO is not available or maybe it is VOC driven or VOC limited.

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Effects of lockdown on Air Quality: Barcelona, Spain

Barcelona, Spain

- Levels of O_3 markedly increased into the city as a consequence of three possible combined causes:
- Firstly, the decrease of NO_x in a VOCs-limited environment (as most urban areas of Europe are) might cause urban O_3 to increase, as opposed to the behavior at the rural-regional background, which is mainly NO_x -limited.
- secondly, the decrease of nitrogen oxide (NO) reduces the O_3 consumption (titration, $NO + O_3 = NO_2 + O_2$), and causes an increase of O_3 concentrations.
- thirdly, the usual increase of insolation and temperatures from February to April leads to an increase in O_3 , especially during Saharan dust episodes (from March 18th to 24th), when the maximum O_3 was recorded.



Source: Querol et al., 2020



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So, the levels of ozone markedly increased in the city as the consequences of three factors, this is a possibility like decrease of NO_x emissions, in VOC limited environment, where VOC governs the production of ozone. So, if VOC is not reduced, so much as NO_x is reduced, then there will not be influence on the ozone production, ozone production will continue.


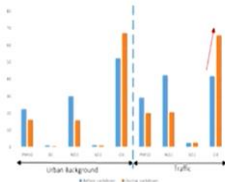
Or secondly this NO consuming ozone that reaction is not going on in a predominant way because NO is not there, it is reduced very much. Then this increase in insolation of temperatures from February to April. So, lot of sunshine is there. So, ozone production related these photochemical reactions were enhanced. So, these three factors may be responsible for ozone increase in the atmosphere.

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Effects of lockdown on Air Quality: Barcelona, Spain

Barcelona, Spain

- A relevant proportion of PM_{10} has a regional background-origin, mostly of secondary PM, and regional air mass transport might have influenced PM_{10} to the point of reducing the effects of local emission abatement.
- Barcelona is a low SO_2 city, with most of this pollutant arising from shipping emissions. This type of ships mostly reduced in the lockdown period.



Source: Querol et al., 2020

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Well, then this PM_{10} related background origin or secondary particulate matter which was because of other pollutants, so, that is also not there due to this low SO_2 , sulphur dioxide, which was related to shipping activities, which was also reduced. So, the secondary sources are also not there, as well as these SO_2 sources are also reduced. So, the concentration is reduced.

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Effects of lockdown on Air Quality: USA

USA

- Air quality was assessed during the COVID-19 pandemic for fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) in the continental United States from January 8th-April 21st in 2017–2020.
- Pollution was considered during the COVID-19 period (March 13–April 21st) and the pre-COVID-19 period (January 8th-March 12th) with 2020 representing 'current' data and 2017–2019 representing 'historical' data.



Source: Ebisu and Berman, 2020

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Well, in USA, from January 8th to April 21st 2017 to 2020, this data was available to get comparison with the, this lockdown period. So, this COVID-19 period March 13th to April 21. And pre-COVID period this January 8th to March 12th. So, these data were compared with the same kind of period for 2017 to 2020. And those data, although it is difficult to call it historical data, but it is still because they were of earlier nature so, they called it historical one.

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Effects of lockdown on Air Quality: USA

USA

- Historical pollution and current pollution concentrations were compared all around the country.

Pollutants	Difference in Historical (2017–2019) and Current Means (January 8 th to April 21 st , 2020) (% change)	
	Pre-Covid 19 period (January 9 – March 12)	Covid 19 period (March 13–April 8)
NO ₂	5.52 %	25.48 %
PM _{2.5}	3.75 %	4.45 %

Source: Ebisu and Berman, 2020



And then they were compared with the data which was observed during pre-COVID and the COVID period. So, NO₂ and PM_{2.5} like pre-COVID period, there was reduction around 5 to 6 percent and PM_{2.5} that was reduced around 4 percent whereas, in COVID period, basically the reduction of NO₂ was quite significant around 26 percent, because in USA a lot of transportation activities goes on when people try to work, they travel long distances, so that was not there. So, it was reduced, PM_{2.5} observed around 5 percent or 4 percent reduction in USA.


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Effects of lockdown on Air Quality: USA

USA

- Decreases in NO₂ are likely associated with reduced vehicular traffic from people working remotely and limited domestic travel.
- Percent change of PM_{2.5} is not as large as that of NO₂, and this may be because PM_{2.5} concentrations are contributed by multiple non-transportation sources, including emissions from food industries and biomass burning.

Source: Ebisu and Berman, 2020



So, the decrease in NO₂; reduced vehicular traffic. So domestic travel and those working remotely they were limited and working remotely was closed that was not there, only limited



domestic travel could be there. So, that was responsible for reduction. The percent of $PM_{2.5}$ is not as large as NO_2 and the reason could be like these multiple non-transportation sources of $PM_{2.5}$ including emissions from like food industries or biomass burning. So, those emissions were there, even when people were living in their own residential areas.

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Effects of lockdown on Air Quality: India

India

- Overall impact of social and travel lockdown was assessed in five megacities of India; Delhi, ✓
Mumbai, Chennai, Kolkata, and Bangalore.
- The spatiotemporal variations in five criteria pollutants over two time periods was evaluated, i.e., ✓
 - March–April 2019 and March–April 2020 and 10th–20th March 2020 (before lockdown) ✓
 - and 25th March to 6th April 2020 (during lockdown).



Source: Sharma and Jain, 2020

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Now, if we come to India, then this overall impact was observed locked down in big mega cities like Delhi, Mumbai, Chennai, Kolkata and Bangalore and there are periods like March to April 2019 and March to April 2020 and then 10th to 20th March 2020. So, before locked down, that data 25th March to 6th April 2020 during the lockdown. So, these data have been compared basically.

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Effects of lockdown on Air Quality: India

Phase Name	Dates	Major restriction or relaxations
Phase 0 (Pre-lockdown)	1–24 March 2020 (24 days)	• No restriction; all activities in business-as-usual mode
Phase 1	25 March–14 April 2020 (21 days)	• All transport, industrial establishment, commercial and private establishments, and hospitality services closed
Phase 2	15 April–3 May 2020 (19 days)	• Allowed: Farming operation, some industries, movement of cargo
Phase 3	4–17 May 2020 (14 days)	<ul style="list-style-type: none"> • Cities are classified into three zones (Red, Orange, and Green). Relaxation of rules in the Green and Orange zones. • Allowed: Activities permitted during Phase 2 and construction activities and movement of vehicles for selected activities permitted. • Restrictions similar to Phase 1 applied in the Red zones
Phase 4	18–31 May 2020 (14 days)	• Allowed: Movement of vehicles without any special conditions along with the opening of the industry.

Lockdown phases in India



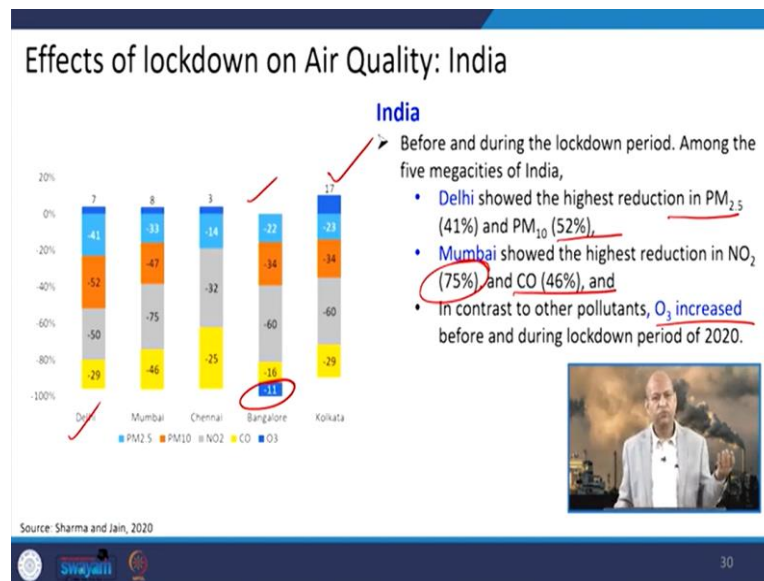
Source: Goel et al., 2021

So, the timeline of different activities like Phase 0, that was the pre lockdown, it was 1st March to 24th March around 24 days of 2020. So, at that time, there were no restrictions, all activities were going on as Business-as-Usual scenario. In Phase 1, 25th March to 14th April, so, 21 days, again, all transport and industrial establishment commercial and private establishment, these hospitality services, all these activities were closed basically.

In Phase 2, 15th April to 3rd May, 19 days so, these farming operations, some industries or movement of cargo that was allowed, because then logistics support was needed for medicines or food supply etc. In Phase 3 for 14 days, 4th to 17th May, then different zones were classified like red zone, orange zone, green zone and according to the number of patients of the COVID those zones were defined and red zones were having, again, the same kind of restrictions, but the green zones and other zones were given some freedom.

Then 18th to 31st May the movements of vehicles without any special conditions doing with like opening of the industries etc, they were allowed. So, in phases, things were closed and things were uplifted.

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Well, the impact is clearly visible, like in Delhi, $PM_{2.5}$ reduction, highest reduction of the $PM_{2.5}$ was observed around 41 percent in Delhi and 52 percent reduction was observed for PM_{10} . In Mumbai reduction of NO_2 was the highest of 75 percent, CO around 46 percent. In contrast to other pollutants, ozone increased as we have seen except in Bangalore, the ozone reduction is there, but in all other cities like Delhi, Mumbai and Kolkata increase of ozone is there, maximum is in Kolkata.

So, these are cities specific characteristics of emissions and air quality. So, more studies are needed to know the reasons, but if we look into like very simple hypotheses and simple guesswork, then in Bangalore maybe the ozone production is VOC limited rather than NO_x limited because due to this lock down, mostly NO_x emissions went down and there may be some VOCs from different sources, maybe natural sources, maybe also there because, Bangalore is quite green and a lot of VOCs may be there because of that.


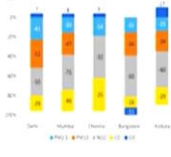
So, but in Kolkata and other we have to see what were the reasons this variation is there that Kolkata observed maximum increase in ozone, whether it was metrological factors or some other factors.

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Effects of lockdown on Air Quality: India

India

- The contrasting trend of O_3 may be due to more favorable conditions for **photochemical reactions** attributed to increased solar insolation and a decrease in NO_2 leading to changes in the photochemical reactions **determining ozone formation and destruction**.
- The air pollution studies conducted in Indian cities showed that **more than 30–50% of NO_x emissions are released by vehicles** especially diesel vehicles compared to petrol driven vehicles.
- This results in reduced NO_x emissions in a **VOC-limited environment**, which could have led to an increase in O_3 concentration.
- It is relevant to point out that the **cities considered in the present study lie in VOC limited regions of India**, thus an increase in the levels of O_3 can be understood by the decline in NO_x emissions.



Source: Sharma and Jain, 2020

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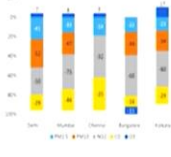
So, in India the increase of ozone was observed and there was reduction in NO_x emissions 30 to 50 percent. And in VOC limited environment, that may be one theory and we do not know which city has this kind of, whether Bangalore has the VOC limited or there are other regions. So, more studies are needed in that sense.

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Effects of lockdown on Air Quality: India

India

- NO_x reduction measures at the urban centres may initially increase the ozone concentrations due to the titration chemistry.
- Sector wise sensitivity analysis shows that the transport sector has the highest potential for control of ozone pollution in India, followed by the industrial sector.



Source: Sharma and Jain, 2020

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Now, if we look into like sector wise sensitivity analysis, then more information can give us better insight so, that we can look into the relationship of reduction of different emissions and impact on the air quality.

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Effects of lockdown on Air Quality: India

India

- It is important to highlight that reduction in $PM_{2.5}$ levels during the lockdown period may also be attributed to reduce NO_2 levels, which played an influential role in the formation of secondary PM.
- Stubble burning has been observed at various places in India like Central India and Southern plains (which includes cities like Bangalore, Chennai) because farmers cannot sell their agricultural residue due to the non-availability of transport.
- This may be another reason for the lesser amount of reduction in air pollutant concentrations in cities in Southern India compared to Northern India.

Source: Sharma and Jain, 2020

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So, these $PM_{2.5}$ levels or NO_2 levels, then secondary particulate matter is also there because of, some gases get transformed into solid, so those relationship may be there and it was also observed that a stubble burning was there in several places in southern part of India. So, at that places different kinds of air quality was observed in comparison to the northern part.

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Learnings from Lockdown

- Lockdown cannot be a long-term or permanent solution to reducing air pollution levels in any geographical area.
- To revive the economy, various sectors would resume operations sooner or later.
- Taking India as an example, post-lockdown, the current Air Quality Index may reach alarmingly high levels due to weather conditions, agricultural and industrial practices, festivals, and various anthropogenic activities.

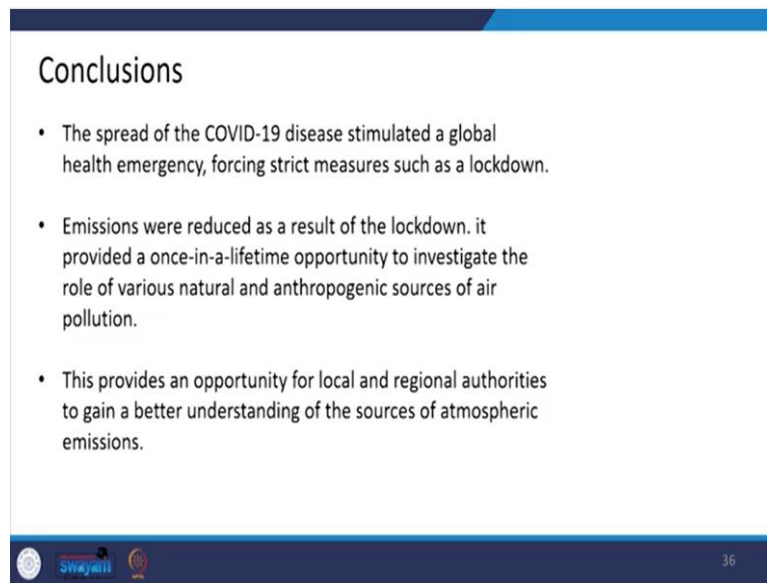
Source: Ebisu and Berman, 2020

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Now, if we look into what are the learnings we can learn from or take away lessons from the lockdown period basically, because it has given unwarranted situation and the closure of different sources and their impact on the air quality? So, can we look into those source specific emissions and their impact on the air quality so, that we can address those sources?

Of course, more source apportionment studies are needed to exactly relate the air quality impact of emissions from those specific sources, but still as we have seen like NO_x emissions reduction, and then ozone increase or PM₁₀, PM_{2.5} reduction, so, that gives a good lesson to learn basically, and so that in agriculture emissions or industrial emissions or different other emissions, we can relate with that.

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Conclusions

- The spread of the COVID-19 disease stimulated a global health emergency, forcing strict measures such as a lockdown.
- Emissions were reduced as a result of the lockdown. it provided a once-in-a-lifetime opportunity to investigate the role of various natural and anthropogenic sources of air pollution.
- This provides an opportunity for local and regional authorities to gain a better understanding of the sources of atmospheric emissions.

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So, in conclusion, at last, we can say that this spread of COVID-19 was a kind of indirect opportunity to see whether there are certain sources, which can be closed and which can be addressed. For example, nowadays, we are going for e-mobility or turning towards renewable resources. So, source specific impact on the air quality can be related with different observations of that period.

And this is a once in a lifetime opportunity, we had just accidentally, but still, we can get some positive lessons and we can learn and we can apply those lessons into the practice so, that we can improve the air quality. So, this is all for today.

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And these are the references and I request that please go through, there are several publications based on this period in observations of air quality and their relationship with sources and emissions. So, those publications may give you more information about why ozone is decreasing at some place or increasing at most of the places or reduction of like NO_x or reduction of PM₁₀ and PM_{2.5}, how much it is related to transport sector, how much it is related to the energy resources or power plants or industrial sector.

So, those kind of information can be gathered from these resources. So, this is all, thank you for your kind attention and see you in the next lecture. Thanks, again.