Air Pollution and Control
Professor Bhola Ram Gurjar
Department of Civil Engineering
Indian Institute of Technology Roorkee
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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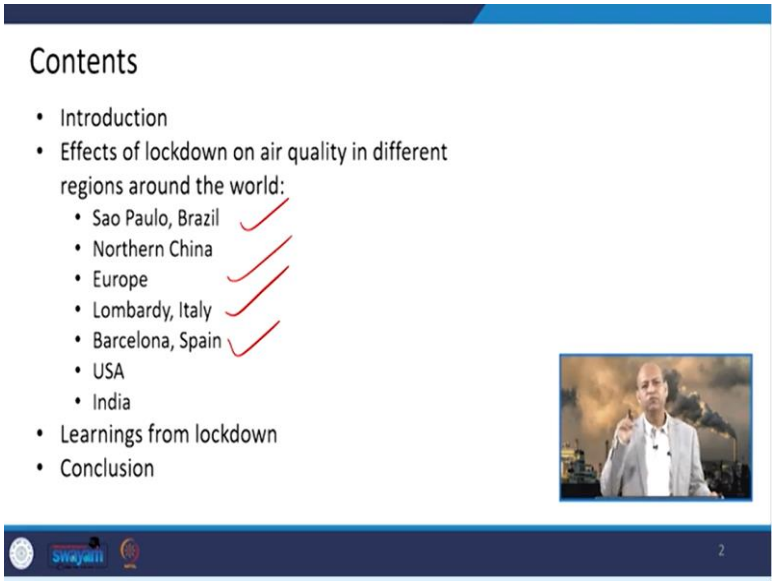

So, we will look into the effect of lockdown on air quality in different countries and regions, like, Sao Paulo in Brazil, we have gathered some data basically. So, this is a kind of indicative or illustrative presentation and taking some inspiration from this, you can further review some literature 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 SO_2, so, that way some signatory pollutants we can try to relate.

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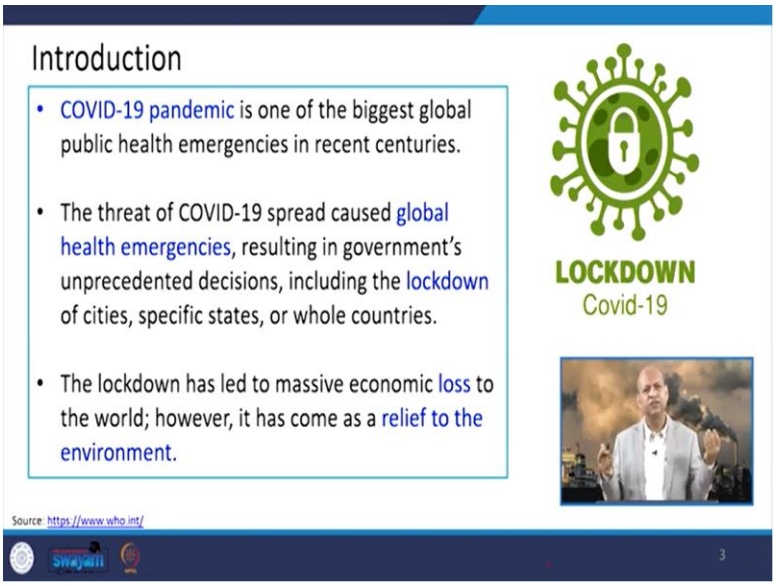

So, you remember this COVID-19 pandemic, this is one of the biggest global public health emergencies in recent centuries as we know in our memory. And the threat of this COVID-19 is spread caused various governments to do lockdown in cities as well as in entire countries sometimes they did for certain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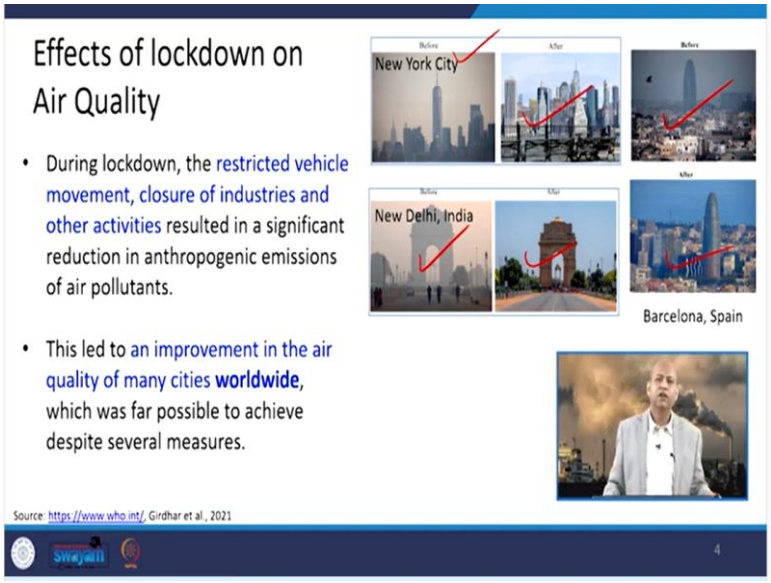

So, during lockdown these visual effects basically, like, because vehicles movements were restricted, industrial production was not there, then other activities were also completely stopped. So, the emissions which were related to those activities went or vanished, or went out.

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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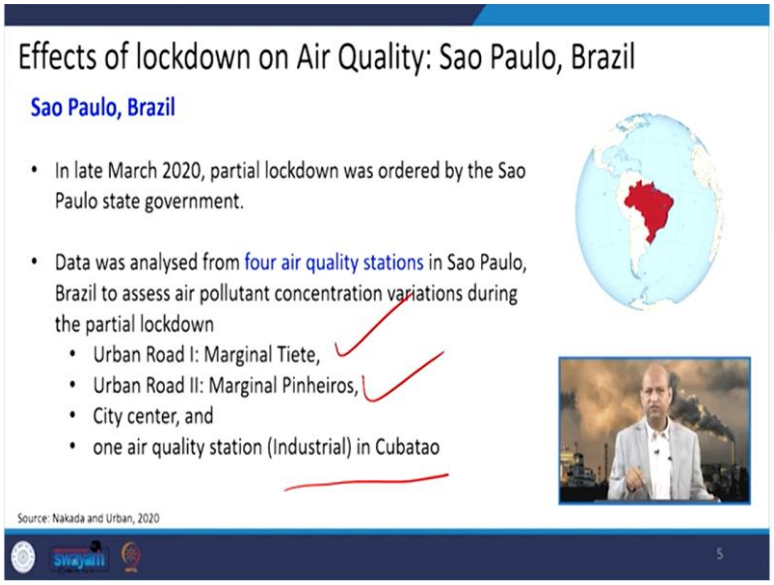

Now, we will try to relate which kind of air pollutants were reduced significantly, and which polluters did not have much effect on that. Now, like one example is Sao Paulo of Brazil. So, there were these four air quality stations where air quality data were borrowed, and these were like urban roads 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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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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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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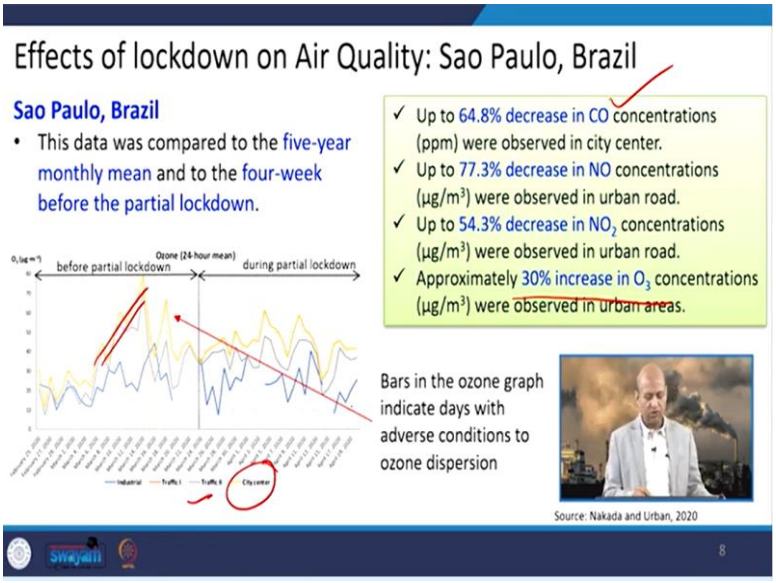

So, effect of lockdown in various ways you can interpret like, there are reduction, significant reduction in CO concentrations, carbon monoxide like 64 percent, NO concentration 77 percent reduction is observed, NO_2 around 54 percent, but ozone, there is no decrease in ozone rather it is increase. And 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 NOx, 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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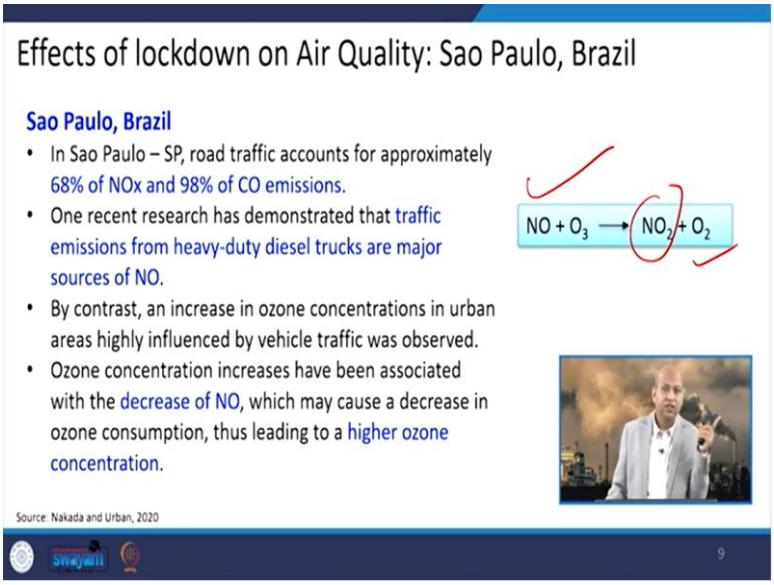

So, basically there are various theories as you know, these precursors if available, only then ozone is produced. So, if precursors are not there, like NOx emissions have been reduced drastically, and especially this titration phenomena happens when lot of NO is emitted by transport sector, if ozone is produced, then it reacts with the NO and it produces NO_2 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 NO_2 is produced which goes into the downwind direction of the cities and when they find lot of sunshine and that NO_2 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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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 $PM_{2.5}$, PM_{10}, NO_2, 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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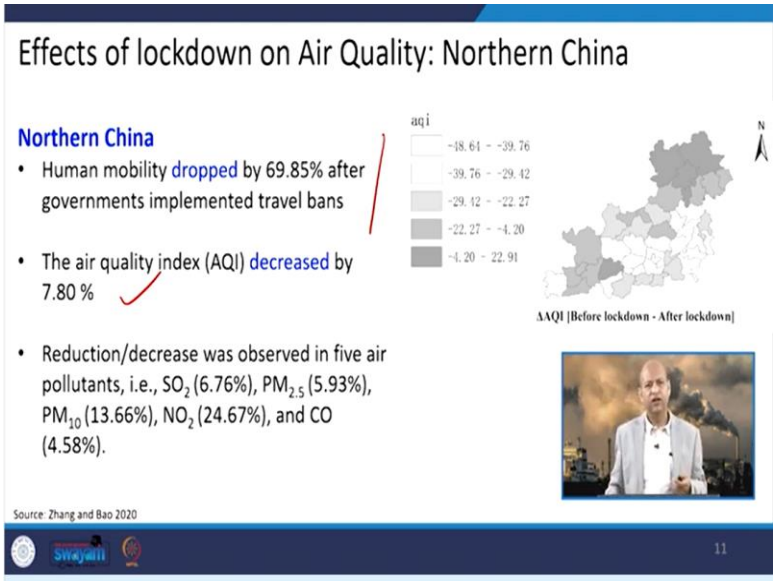

And then there was this drop in human activities or mobility related activities around 70 percent and that resulted into AQI decrease around 7.80 percent, and reduction in concentration of SO_2 like around 7 percent, $PM_{2.5}$ around 6 percent, PM_{10} around 14 percent and NO_2 around 25 percent and 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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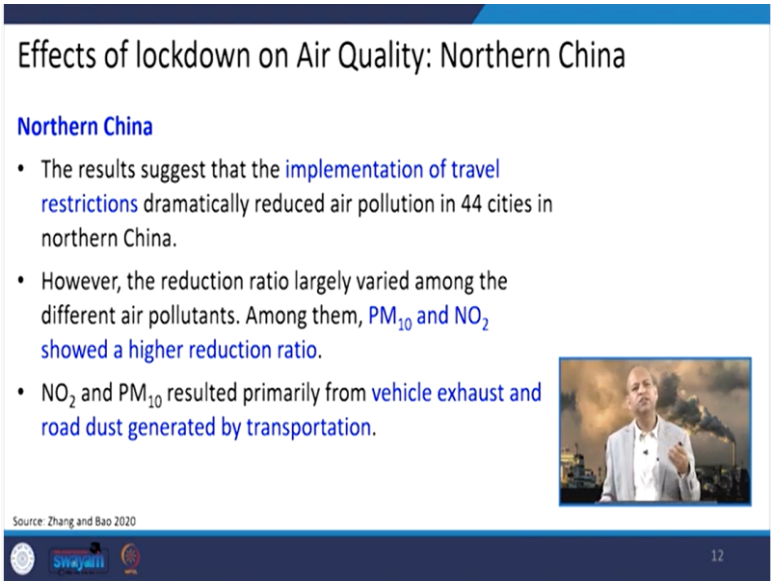

So, the results suggest that implementation of those travel restrictions have resulted in reduction of NO_x emissions or CO emissions even fine particles like $PM_{2.5}$ and PM_{10}.

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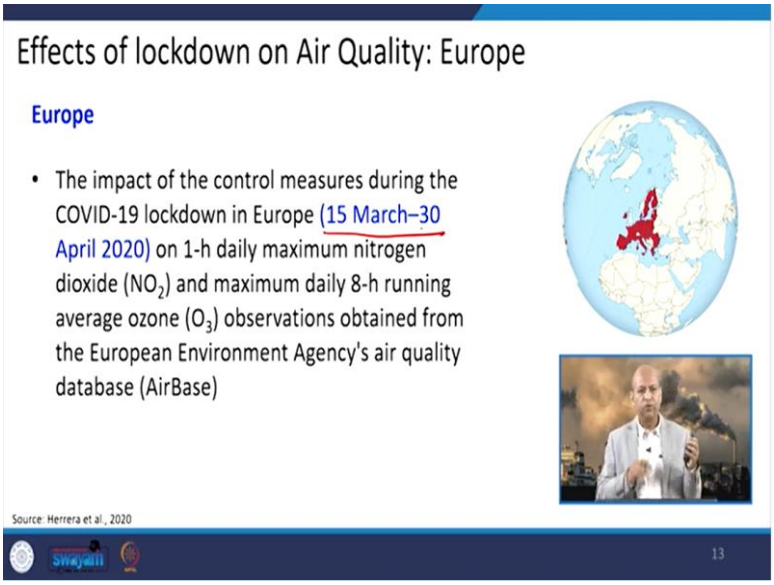

If we talk about the Europe, then the impact of these control measures for the COVID-19 from 15th March to 30th April, for one-hour daily data of nitrogen dioxide and ozone these two data were observed to see what was the impact on the air quality.

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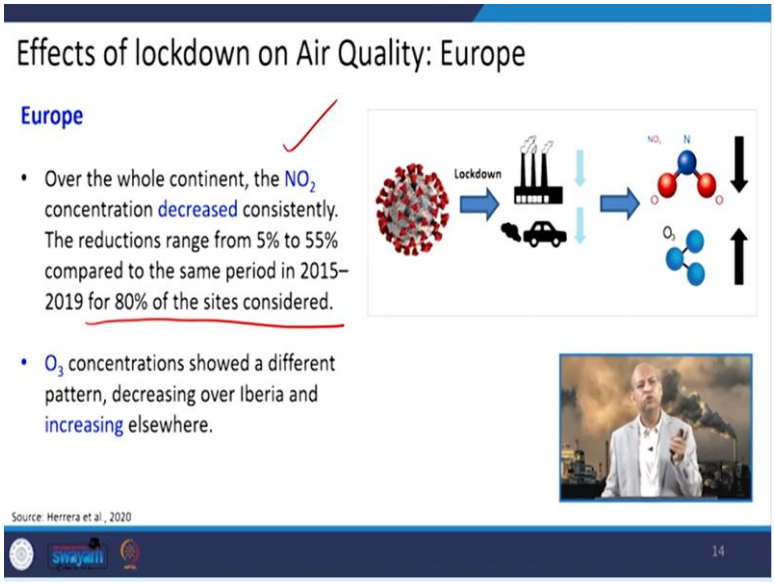

So, in Europe basically, if you look into this entire region of several sites, it was observed that NO_2 concentration decreased in a big range like 5 percent to 55 percent in 80 percent of the sites of the observations. But in case of ozone basically, there was at a particular site of this Iberia, the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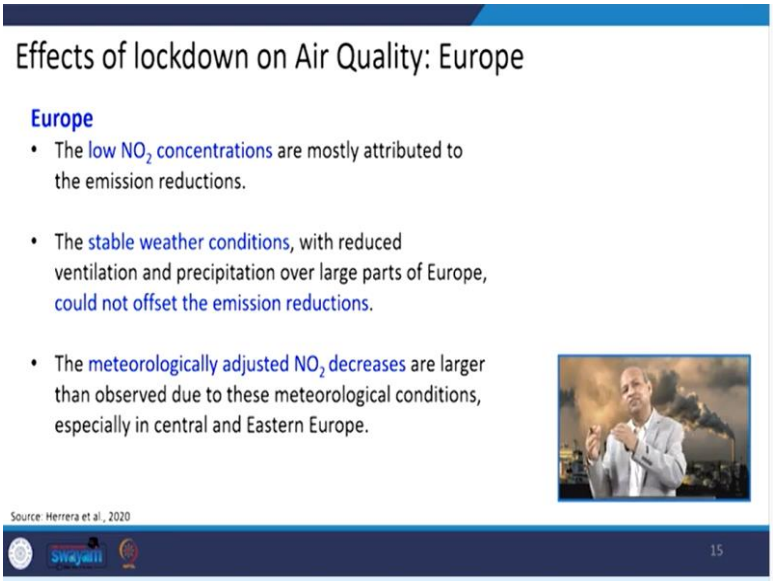

So, this is something which we have to look into, like there was a concentration of NO_2 decrease was there, but decrease, maybe, somewhere less, the reason could be like a stable weather, if that stable weather was not there, if we do not account for those metrological factors, then the decrease could be much higher, but it is still, there is a good range 5 percent to 55 percent at different locations.

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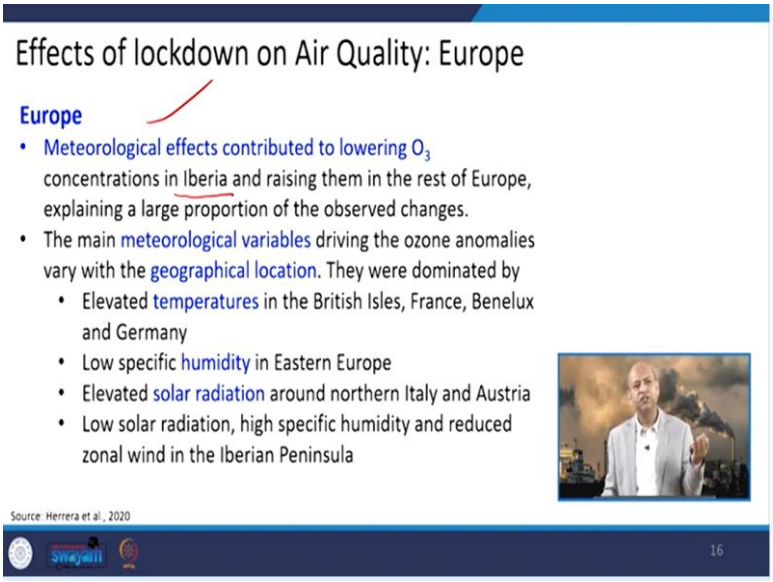

But at a particular site of Iberia, this ozone decreasing was observed and that was because of some metrological effects, because it is a photochemical reaction it needs not only the precursors, but also the sun shine and those kinds of issues are there. So, because of this

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 NOx 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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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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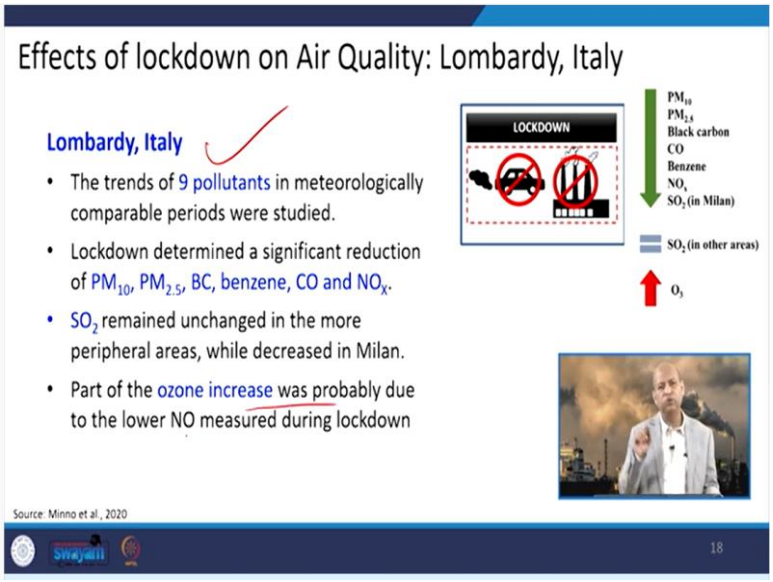

So, the trends of the 9 pollutants were observed during this lockdown period that is PM_{10}, $PM_{2.5}$, black carbon, benzene, carbon monoxide or NOx emissions. And it was found that SO_2 there was not big change, SO_2 remained unchanged in this peripheral area. So, that was maybe like residential 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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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, SO_2 reduction was also observed.

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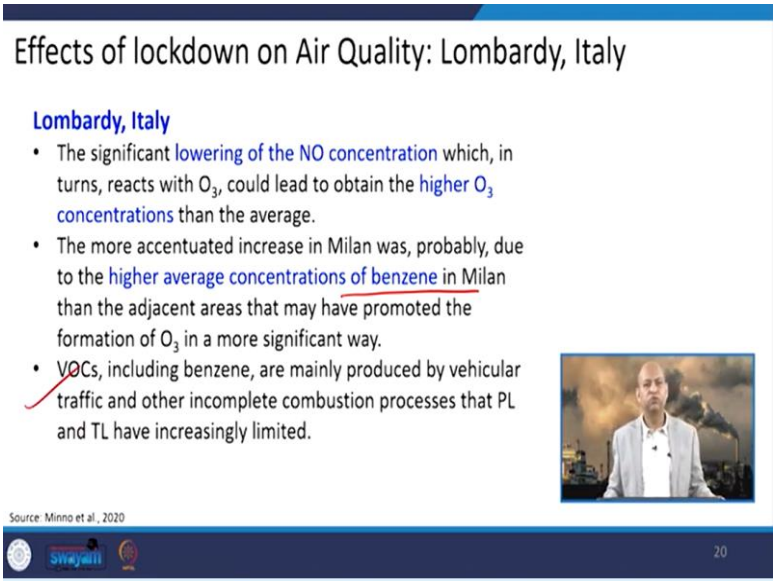

Well, if we talk about this ozone, so, the significant lowering of this NO concentration which consumes ozone due to titration kind of reaction so, this low NO resulted into increase in the ozone concentration because there is no NO to consume ozone and ozone buildup was there because other factors were 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 NOx 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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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 PM_{10}, NO_2, SO_2, and ozone for this city of Barcelona.

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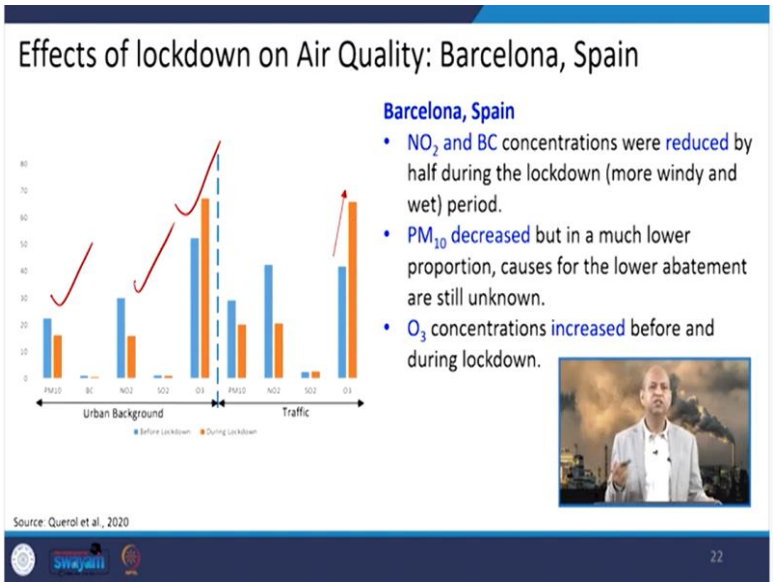

And there is a reduction in PM_{10} or NO_2, SO_2 and BC there is because emissions are less. So, that significant decrease not observed, but in case of PM_{10} and NO_2 is visible. In case of ozone, it is, like whether it is urban background or the traffic related background, it is increase is there, ozone production the same trend, because NO is not available or maybe it is VOC driven or VOC limited.

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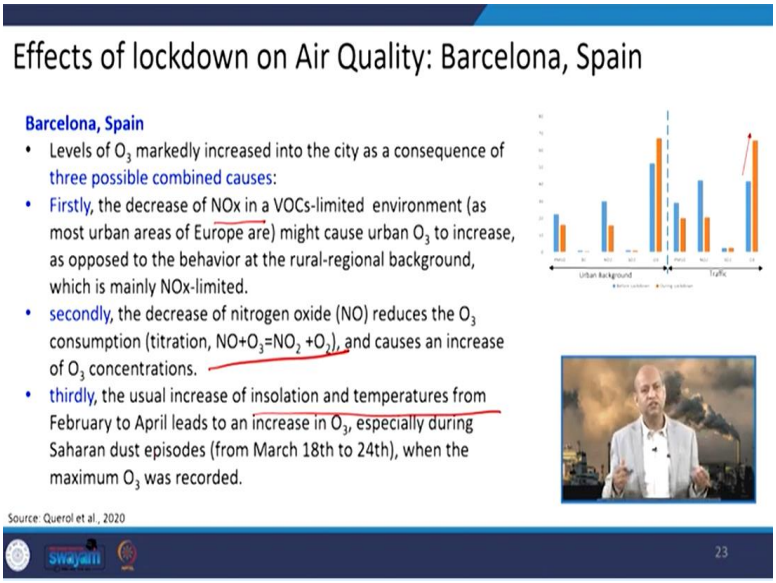

So, the levels of ozone markedly increased in the city as the consequences of three factors, this is a possibility like decrease of NOx emissions, in VOC limited environment, where VOC governs the production of ozone. So, if VOC is not reduced, so much as NOx is reduced, then there will not be influence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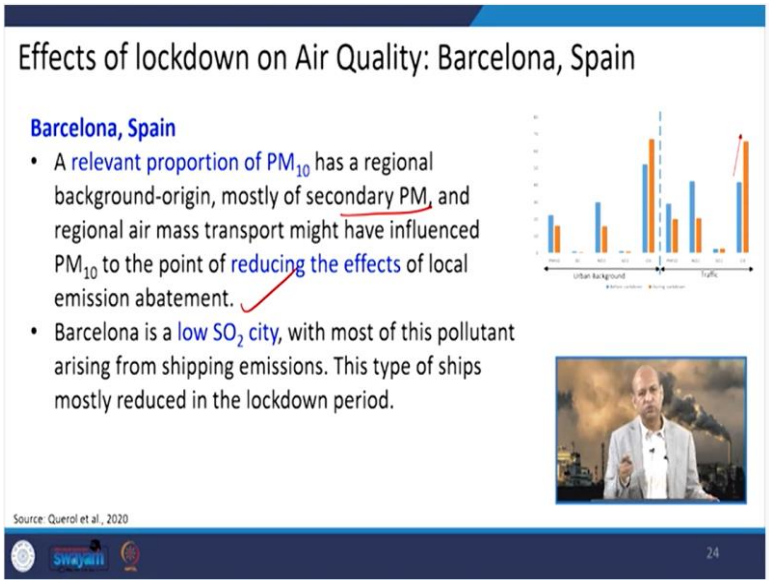

Well, then this PM_{10} related background origin or secondary particulate matter which was because of other pollutants, so, that is also not there due to this low SO_2, sulphur dioxide, which was related to shipping activities, which was also reduced. So, the secondary sources are also not there, as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

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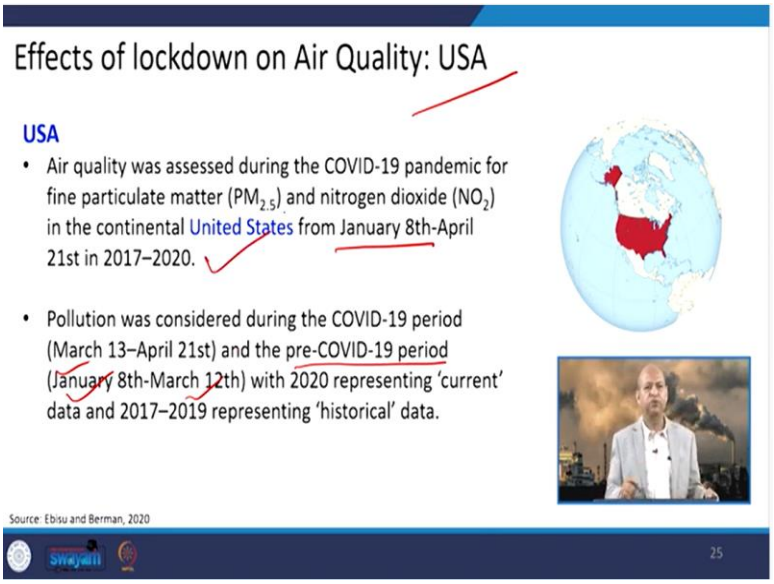

Well, in USA, from January 8th to April 21st 2017 to 2020, this data was available to get comparison with the, this lockdown period. So, this COVID-19 period March 13th to April 21. And pre-COVID period this January 8th to March 12th. So, these data were compared with the same kind of period for 2017 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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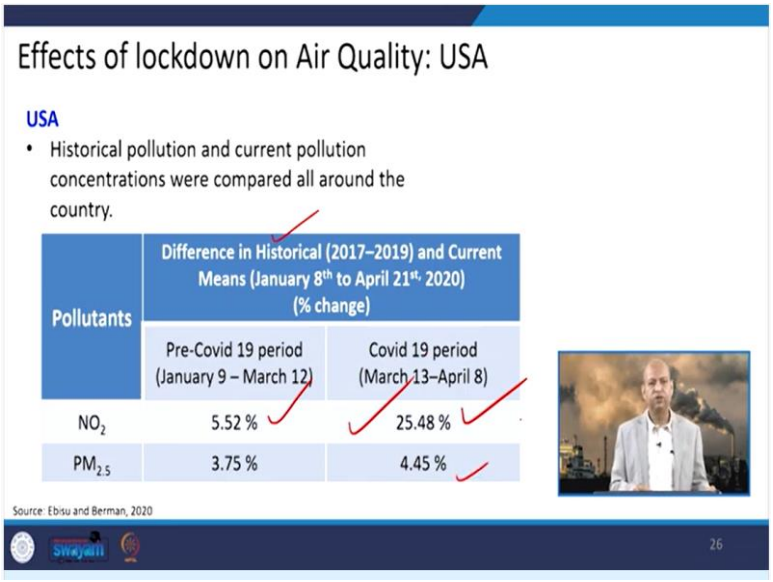

And then they were compared with the data which was observed during pre-COVID and the COVID period. So, NO_2 and $PM_{2.5}$ like pre-COVID period, there was reduction around 5 to 6 percent and $PM_{2.5}$ that was reduced around 4 percent whereas, in COVID period, basically the reduction of NO_2 was quite 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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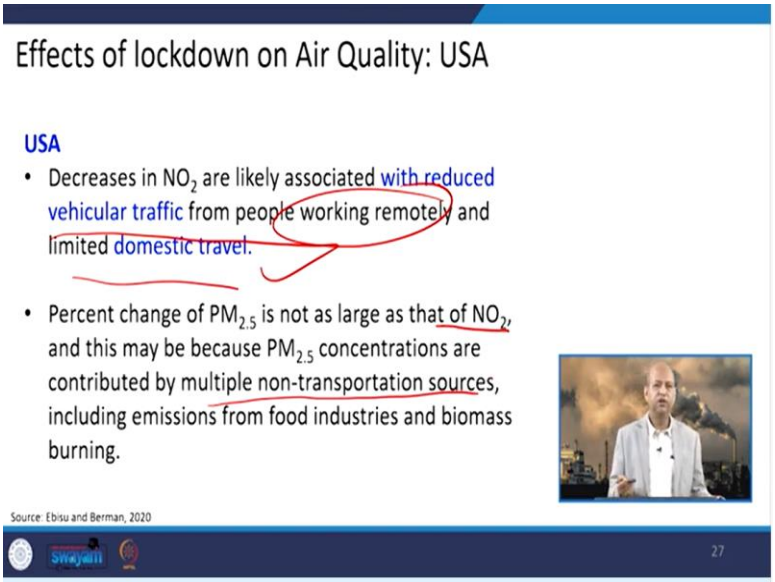

So, the decrease in NO_2; reduced vehicular traffic. So domestic travel and those working remotely they were limited and working remotely was closed that was not there, only limited

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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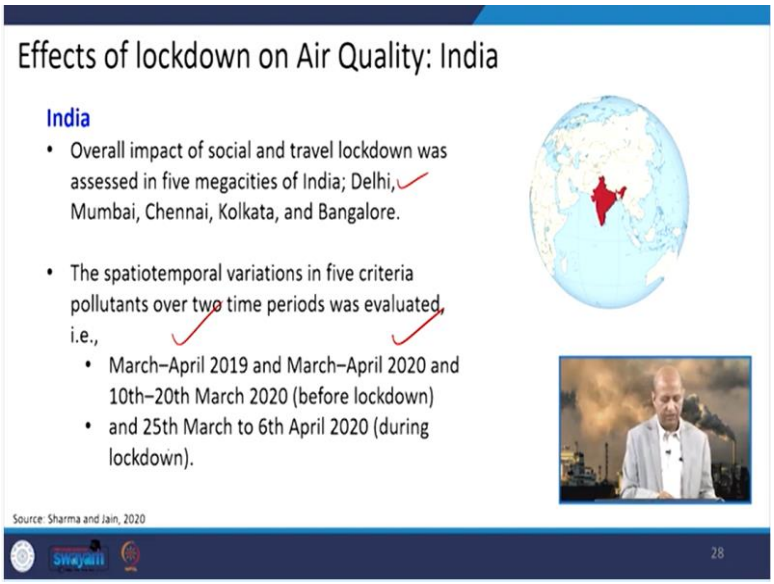

Now, if we come to India, then this overall impact was observed locked down in big mega cities like Delhi, Mumbai, Chennai, Kolkata and Bangalore and there are periods like March to April 2019 and March to April 2020 and then 10^{th} to 20^{th} March 2020. So, before locked down, that data 25^{th} March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

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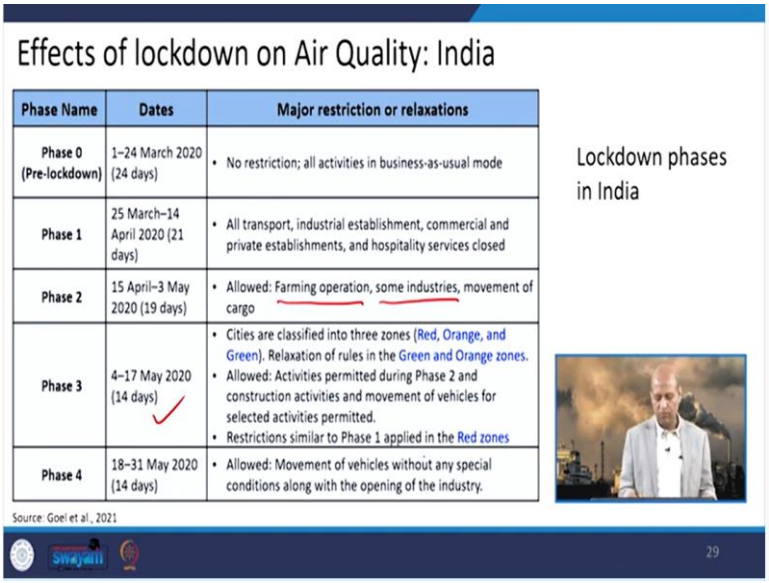

So, the timeline of different activities like Phase 0, that was the pre lockdown, it was 1st March to 24th March around 24 days of 2020. So, at that time, there were no restrictions, all activities were going on as Business-as-Usual scenario. In Phase 1, 25th March to 14th April, so, 21 days, again,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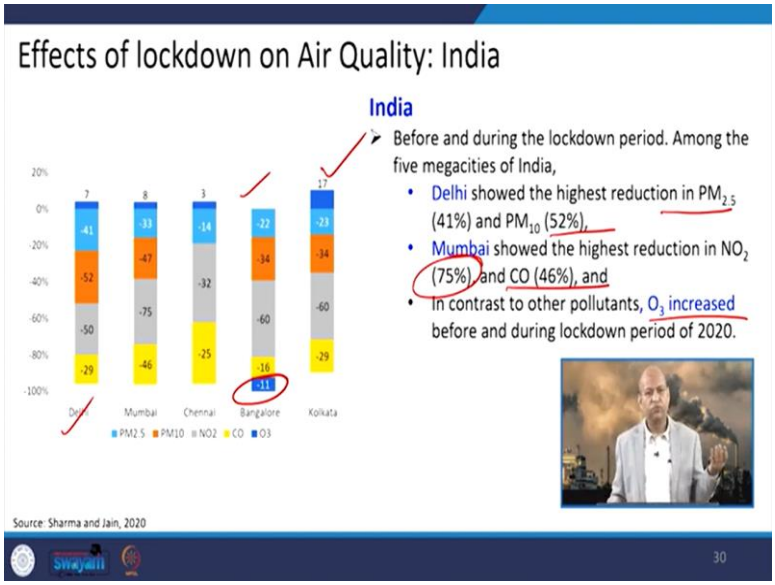

Well, the impact is clearly visible, like in Delhi, $PM_{2.5}$ reduction, highest reduction of the $PM_{2.5}$ was observed around 41 percent in Delhi and 52 percent reduction was observed for PM_{10}. In Mumbai reduction of NO_2 was the highest of 75 percent, CO around 46 percent. In contrast to other 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 NOx limited because due to this lock down, mostly NOx 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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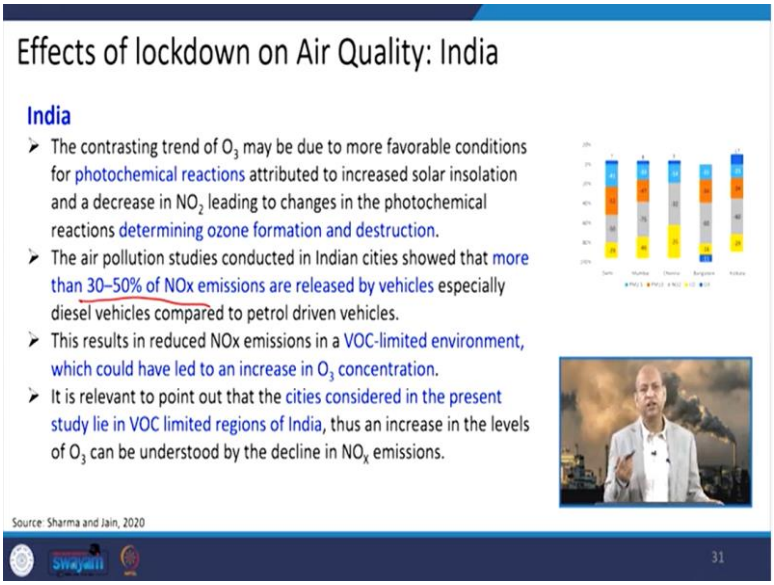

So, in India the increase of ozone was observed and there was reduction in NOx emissions 30 to 50 percent. And in VOC limited environment, that may be one theory and we do not know which city has this kind of, whether Bangalore has the VOC limited or there are other regions. So, more studies are needed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

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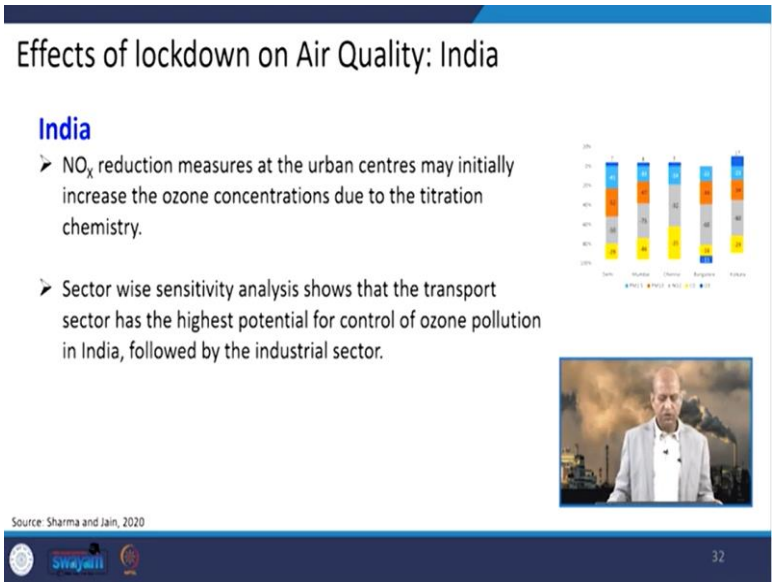

Now, if we look into like sector wise sensitivity analysis, then more information can give us better insight so, that we can look into the relationship of reduction of different emissions and impact on the air quality.

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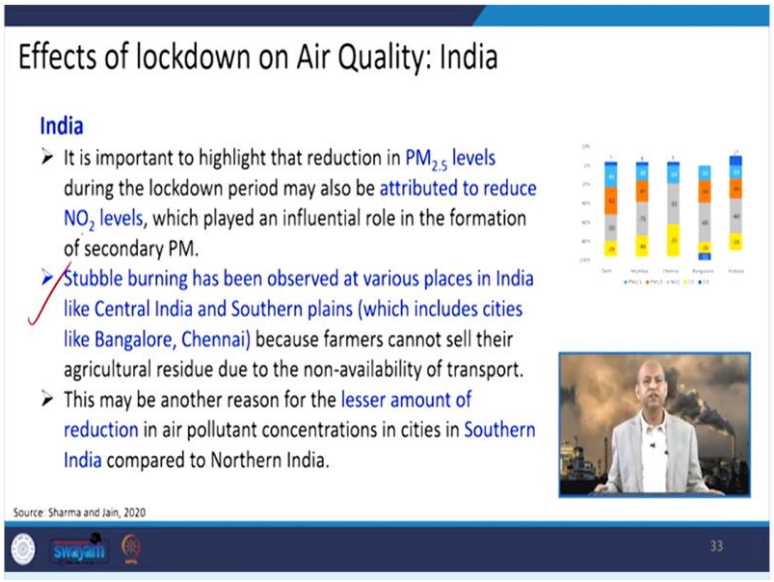

So, these $PM_{2.5}$ levels or NO_2 levels, then secondary particulate matter is also there because of, some gases get transformed into solid, so those relationship may be there and it was also observed that a stubble burning was there in several places in southern part of India. So, at that places different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

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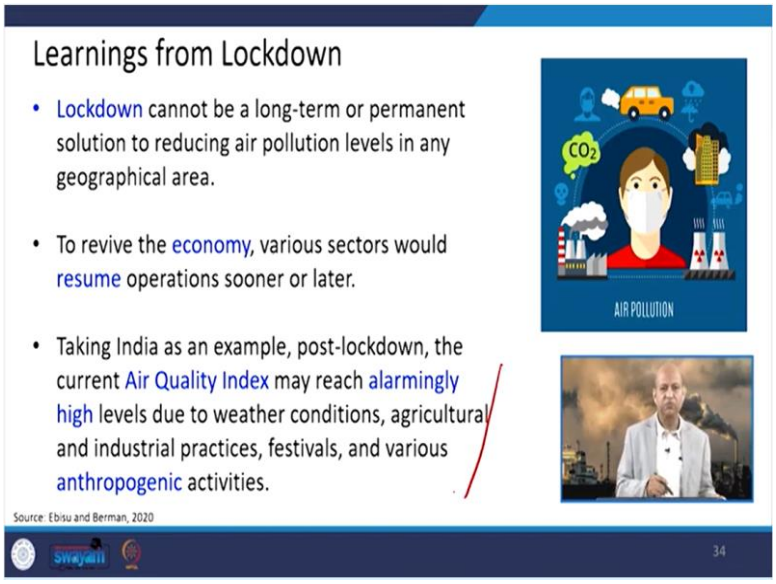

Now, if we look into what are the learnings we can learn from or take away lessons from the lockdown period basically, because it has given unwarranted situation and the closure of different sources and their impact on the air quality? So, can we look into those source specific emissions and their impact 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 PM_{10}, $PM_{2.5}$ 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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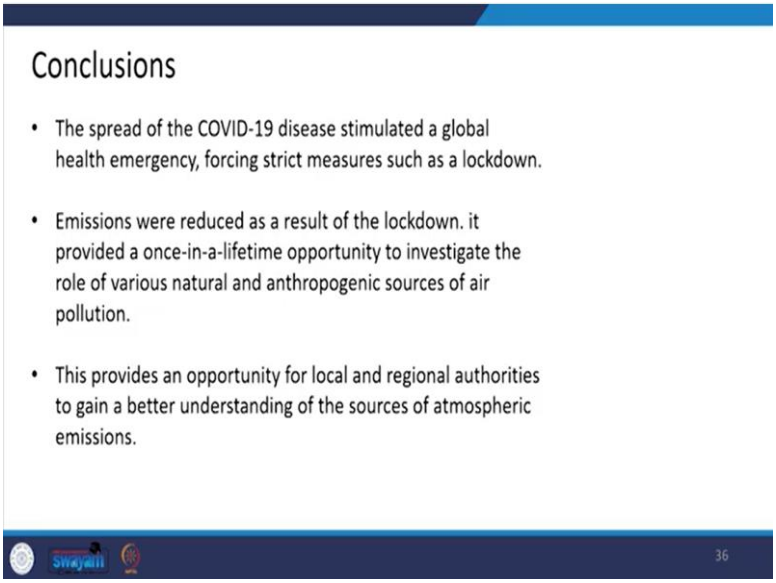

So, in conclusion, at last, we can say that this spread of COVID-19 was a kind of indirect opportunity to see whether there are certain sources, which can be closed and which can be addressed. For example, nowadays, we are going for e-mobility or turning towards renewable resources. So, source specific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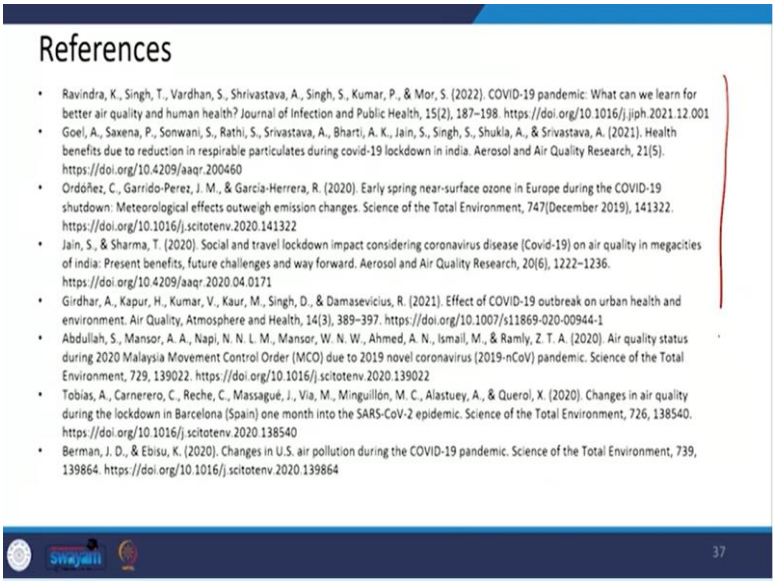

And these are the references and I request that please go through, there are several publications based on this period in observations of air quality and their relationship with sources and emissions. So, those publications may give you more information about why ozone is decreasing at some place or increasing at most of the places or reduction of like NOx or reduction of PM10 and PM2.5, 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.