Air pollution and Control
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Lecture 19
Assimilative Capacity of an Airshed

Hello friends, so far, we have discussed dispersion modeling techniques like Gaussian dispersion modeling for point source, line source, areas source. Now, today we would like to discuss about Assimilative Capacity of an Airshed, you might have heard about watershed. So, the catchment area and we look into all kinds of variables there like precipitation and runoff, etc and the carrying capacity of a particular ecosystem like lake or river, how much pollution it can digest within a given time framework.

Similarly, the airshed also has the carrying capacity or assimilative capacity. That means, we can discharge certain amount of air pollutants into it and then it can clean itself, there is some self-cleansing capacity you can say because of dispersion, dilution those natural phenomena which occurs all the time. And then after that it is again clean atmosphere. And if it is beyond the assimilative capacity or beyond the carrying capacity, then the atmosphere will be polluted it will have poor air quality.

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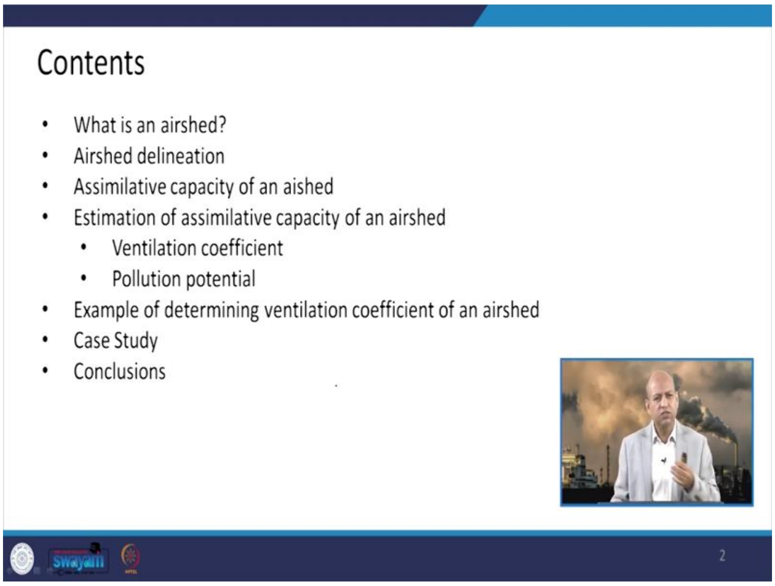

So, first of all we will discuss about what is the airshed then, demonstration or explanation of the airshed and assimilative capacity of an airshed we will define, then we will see like how to estimate the assimilative capacity of an airshed through techniques of ventilation coefficient or pollution potential.

Then we will see one example of determining ventilation coefficient of an airshed, then we will have a case study, so that you can visualize what is the way to estimate the assimilative capacity of an urban airshed or simply airshed and then we will conclude.

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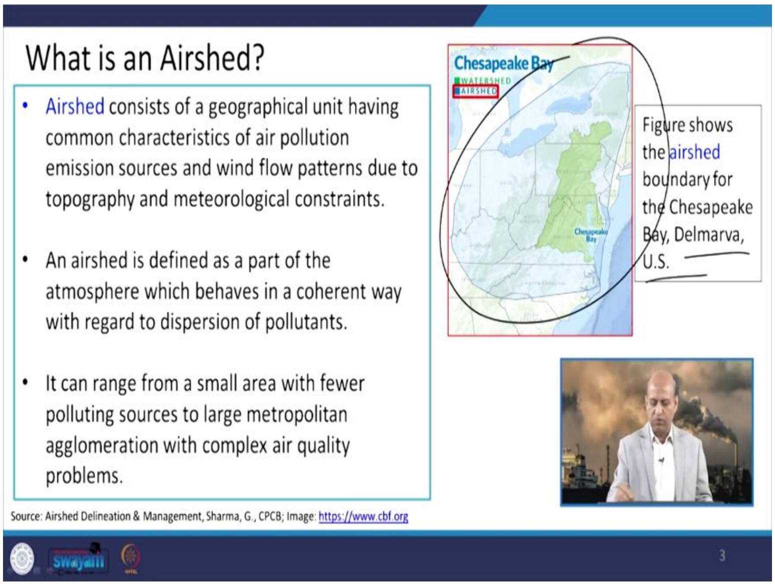

So, when we talk about the airshed, what is airshed? Airshed is a geographical unit. An area within some length, breadth, or height you can say, topography is also there. So, this is a geographical unit which has common characteristics of air pollution emission sources and wind flow patterns due to certain topographic features or certain metrological constraints.

So, they have uniform kind of or common characteristics of air quality or emission sources and wind patterns like wind velocity, direction and meteorological parameters like humidity or temperature profile all those things. So, within that particular area, you will find certain plus minus maybe there, certain variability can be there, but a kind of uniform. For example, you can distinguish between a valley.

So, valley area where there are certain ways where this air will take the pollution from one place to another there will be valley effect, there will be inversion phenomena, diurnal inversion occurs because of changing of the solar insolation during morning time then evening time and then daytime. So, that is the variation which is different than the plains and which is also different than the coastal regions.

So, there are certain regions or geographical area which has common characteristics and we call them as an airshed that atmosphere. It will also have watershed, it will also have other things, so many several ecosystems, sub ecosystems or larger ones, but it also has airshed. So, we can define within a boundary and this airshed can be defined as a part of the atmosphere which behaves in a coherent way.

As I said, it will have some common characteristics with regard to the dispersion of the pollutants, it will have certain view of dispersion, dilution of the pollutants because of those metrological factors, it can range from a small area with fewer polluting sources to a large metropolitan agglomeration with complex air quality problems. So, like here you can see this figure which shows the airshed boundary for this Chesapeake Bay in the United States. So, this is the boundary layer it is shown here.

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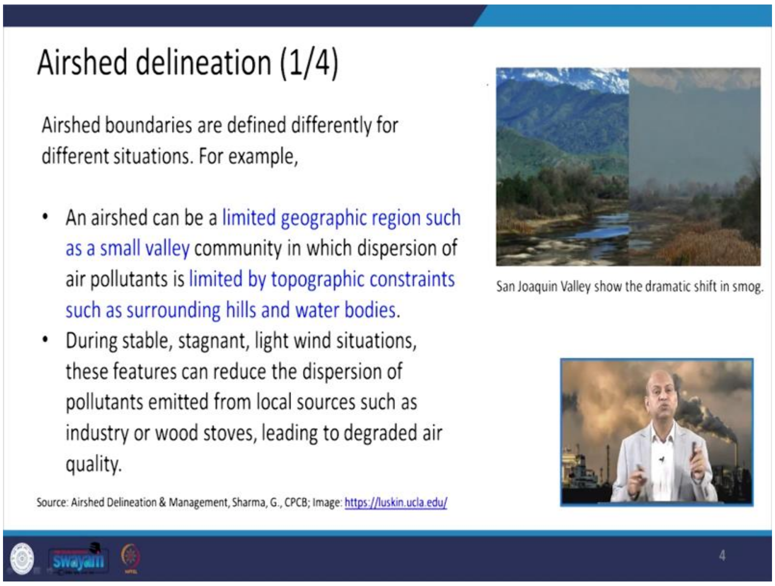

Well, then this airshed boundaries can be defined differently for different situations. For example, we can say that an airshed which is limited by geographical regions such as a small valley as I just tried to illustrate it, or in which dispersion of air pollutants is limited by topographic constraints, such as surrounding of the hills, water bodies etc.

Then during stable, stagnate, light wind situations, these particular features of the valley effect or lake effect can reduce the dispersion of pollutants which are emitted through local sources for example, there may be some industries. Or wood stoves like in villages people use wood or cow dung or those kind of bio mass for meeting their needs for the energy and this can lead to the degraded air quality because it does not disperse So, quickly as it happens in plain areas.

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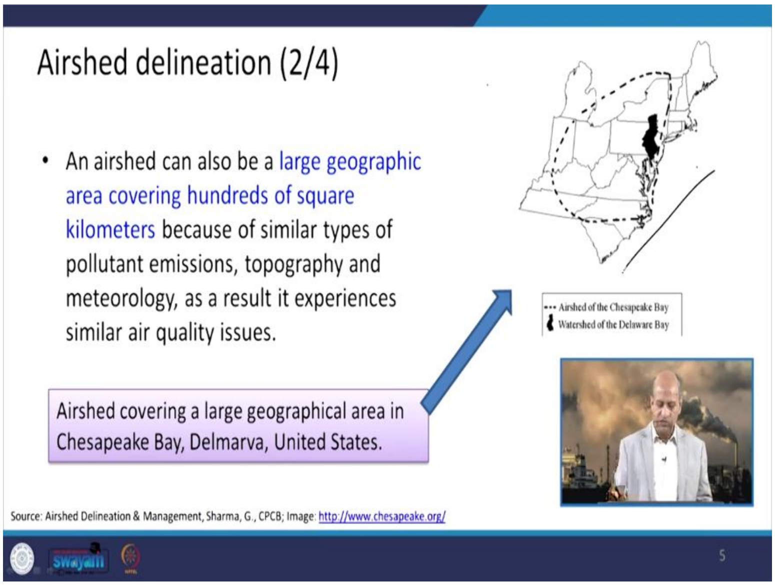

The next is like airshed can also be a large geographical area covering hundreds of square kilometres because of similar type of pollutant emission sources, topography and meteorology. As a result, it experiences similar air quality issues. So, wherever you go, you will find similar kinds of emission sources like for example, in a city you will find those vehicular emission sources, industries maybe there, domestic sources can be there.

But another city can have different kinds of sources they can have different kind of airshed, so that can vary. And this airshed this covering large geographical areas we have seen this kind of limitation or boundaries can be drawn to represent the airshed.

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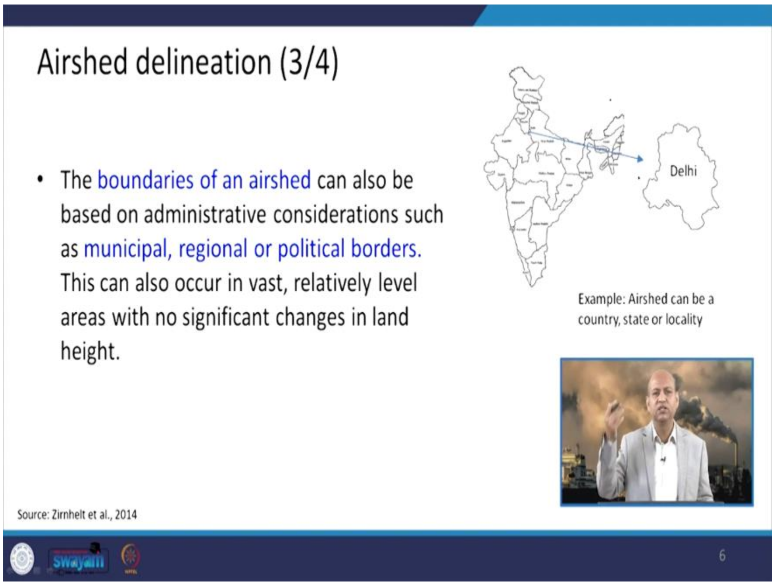

And airshed has this height within this atmosphere length, width, etc. The boundaries of airshed can also be based on administrative considerations. For example, municipal corporation, regional or political borders. So, this can also occur in vast relatively level areas with no significant changes in land height like Delhi you can call one airshed. You can then call some coastal regions airshed.

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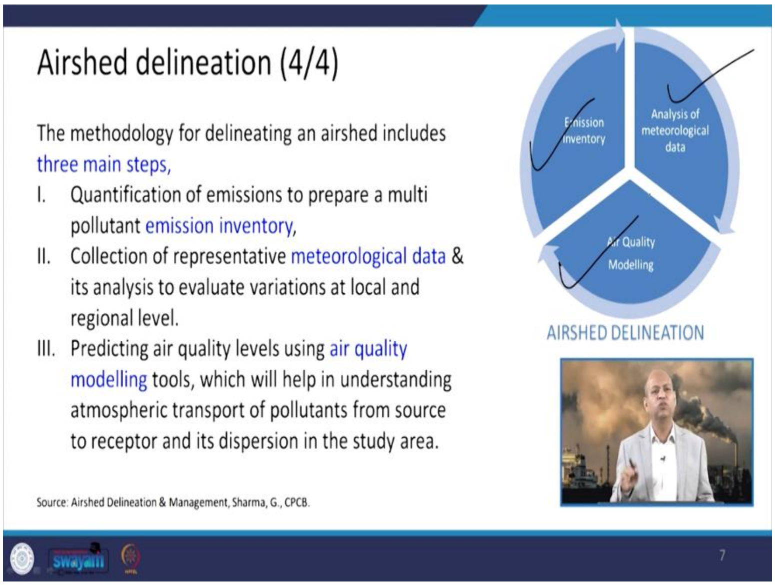

Then the methodology for delineating this airshed includes three main steps. First, we have to quantify emissions to prepare a multi pollutant emission inventory. Without emission inventory, it would be difficult to know how many sources, it would be difficult to know how many sources are there and how much amount of pollutants are coming which kind of pollutants are coming from which source.

Then collection of representative metrological data, we cannot have each and every corner, these mythological towers, but representative means like industrial area, commercial area, then residential areas, educational areas. So, because every area has different characteristics, so representative metrological data can be collected within those particular areas.

And then we have to analyze, we have to evaluate those variations of the local and regional level metrological parameters, then we need to predict air quality levels using air quality dispersion modeling tools, which we have studied already. So, that can help in understanding that atmospheric transport of pollutants or transformation of pollutants also if you use some chemical transportation model from source to receptor and its dispersion in the study area.

So, you can see this emission inventory then analysis of metrological data, collection and analysis, then air quality modeling, all these three aspects are there for delineation of airshed related information.

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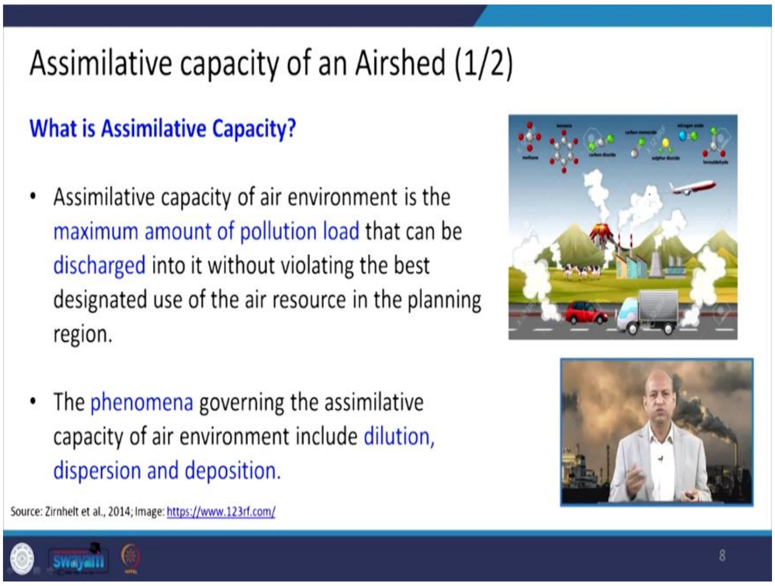

Then we come to the assimilative capacity of an airshed. It is also known as carrying capacity, many authors and researchers use different kinds of nomenclature. So, please do not get confused, this is one and the same thing. But of course, we have to see other parameters like pollution potential and those things we will come into shortly.

So, the assimilative capacity of an air environment is the maximum amount of pollution load that can be discharged into that atmosphere without violating the best designated use of the resource in the planning region, means, that means you can discharge or you can emit a lot of pollution until it is within the those national air quality standards, it should not violate, it should not exceed those limits, then assimilative capacity is up to that limit.

If it exceeds then it has crossed the assimilative capacity, that it means, the phenomena governing the assimilative capacity of your environment includes like dilution, dispersion and deposition even like dry deposition or where deposition all those things already.

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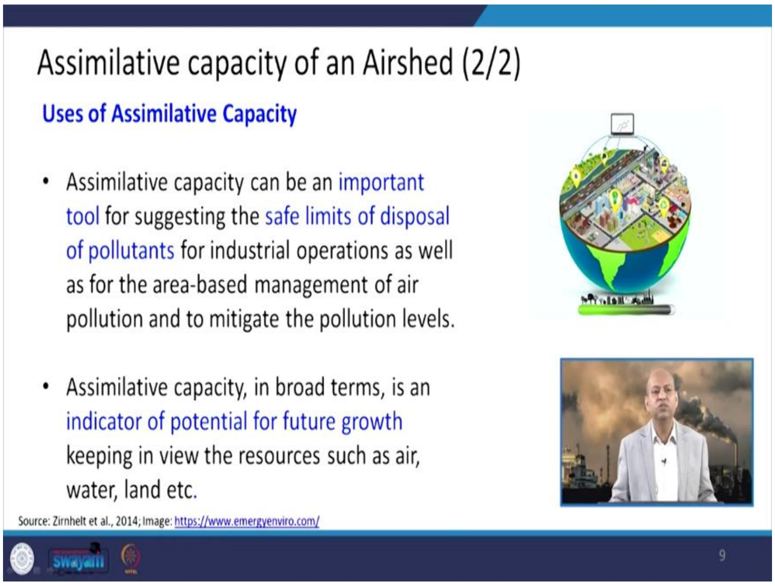

Well, then what are the uses of this assimilative capacity? Why do you want to calculate it? So, we should know about this feature, that this assimilative capacity can be an important tool for suggesting the safe limits of disposal of pollutants for industrial operations or for planning some industrial area as well as for area-based management of air pollution and to mitigate the pollution levels.

So that way, if you are planning new city, new industrial area, then assimilative capacity you have to estimate that this much of pollution load can be discharged into the atmosphere. You need to know the boundary or background information of the air quality and then you do modeling efforts, we will see shortly that how do we calculate so that you can know how much pollution load can be allowed to emit different kinds of pollutants.

Well, the assimilative capacity in broad terms is an indicator of potential for future growth keeping in view the resources such as air water and land because air pollution also can pollute the water bodies it can also pollute the land.

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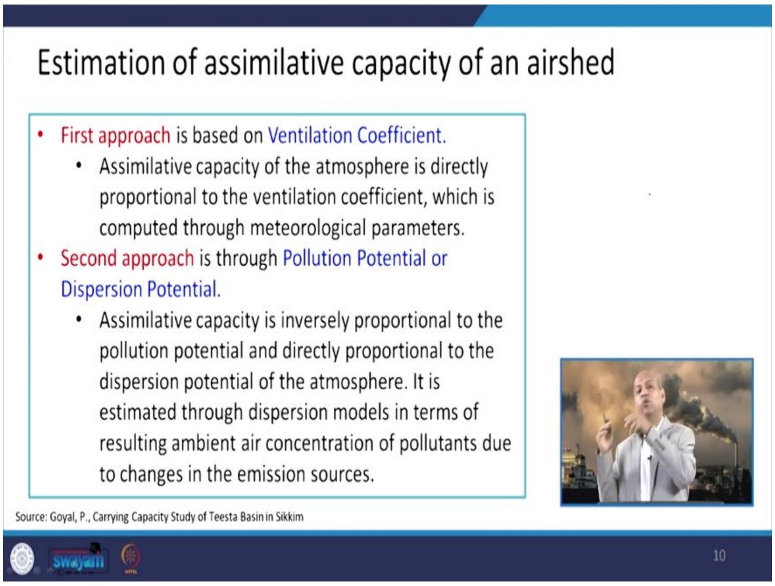

As these are the integrated approach of the ecosystem. Well, then there are approaches how to estimate the assimilative capacity. So, the broadly two approaches are there, first approach is based on the ventilation coefficient, what is ventilation coefficient, we will know. So, this assimilative capacity in the atmosphere is directly proportional to the ventilation coefficient, which is computed through metrological parameters like maximum mixing depth or maximum mixing height and the average velocity within that depth or height, we multiply that.

So, that particular thing is known as the ventilation coefficient. Then second approach is through pollution potential or dispersion potential, these are two different opposite meanings, you should be careful about. Like assimilative capacity is inversely proportional to the pollution potential and directly proportional to the dispersion potential of the atmosphere.

So, it is estimated through dispersion models in terms of resulting ambient air concentration of pollutants due to change in the emission sources, only then you would like to estimate, is not it? So, you first one the emission dispersion models and then how much air quality is there. So, the dispersion potential if it is more because of wind velocity because of certain topographical features, then it will have more assimilative capacity. Pollution potential means if there are more sources, if there are more chances of emissions of the air pollutants, then we will have the less assimilative capacity.

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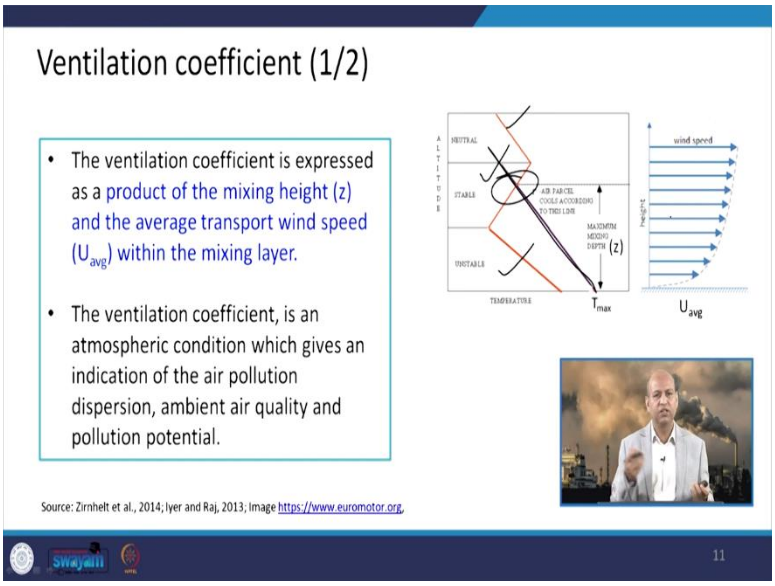

Well, so, the ventilation coefficient we want to study, we want to know. So, you can see this is you know this environmental lapse rate, it can be monitored by some way like balloons etc, or those sodars. Then we need to this we have to have this particular adiabatic lapse rate related profile. So, wherever they intersect up to that depth, we or height we can call it maximum mixing depth.

So, we can calculate it easily, we need to have the actual profile of the environmental lapse rate. So, the way temperature is decreasing or increasing with the height. So, this this one is the actual, and this is the adiabatic lapse rate related. So, wherever they intersect that would be the height which is maximum mixing height, or maximum mixing depth. And then we have to know the wind speed at different heights up to the height, as wind speed increases with the height.

So, we will have different wind disputes at different heights. So, we need to know the average wind speed within that particular depth, or height of the maximum mixing depth. So, that average speed of the wind is multiplied by this maximum mixing depth, then we get the ventilation coefficient. So, the ventilation coefficient basically is an atmospheric condition which gives an indication.

It is difficult to know how much pollution it can take, but it can really give us some sense that the air pollution dispersion, ambient air quality and pollution potential will be more or less something like that.

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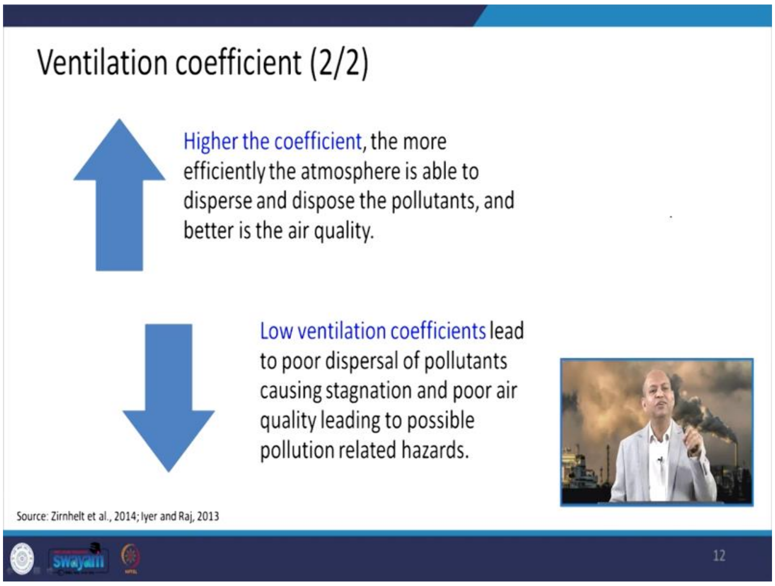

Well, so, the higher the coefficient, higher the ventilation coefficient, the more efficiently the atmosphere is able to disperse, and dispose the air pollutants, and better is the ambient air quality. And low ventilation coefficient, this lead to the poor dispersion of pollutants causing stagnation and poor air quality, leading to possible pollution related hazards.

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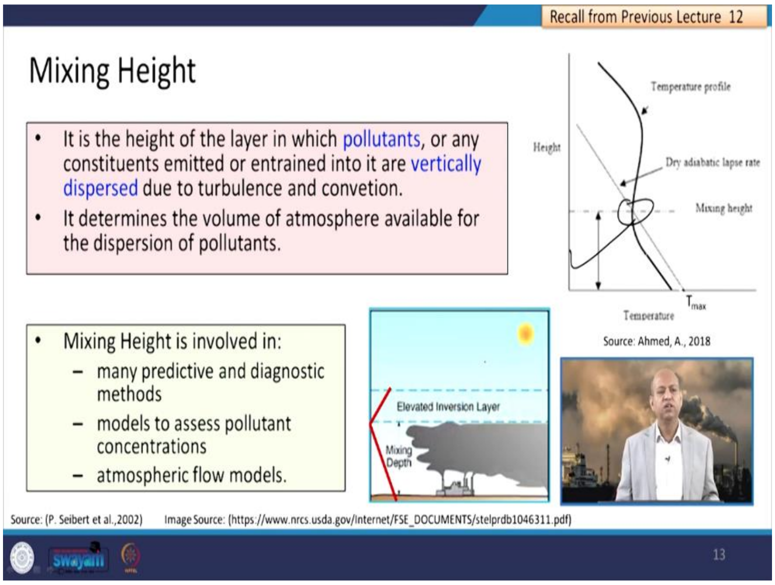

So, the mixing height as we have seen, you can have this particular temperature profile, then draw the radiometric lapse rate, and intercept it, then measure this one. You can know this one also like there is elevated inversion layer. So, below this mixing depth is there because pollution does not cross this inversion layer. And there are various usage of this mixing height basically it is used or involved in many predictive and diagnostic methods.

Because modeling techniques need this mixing depth for several calculations. It also need to assess pollutant concentrations in models. So, we use this particular thing, atmospheric flow models all these kinds of tools use the mixing depth.

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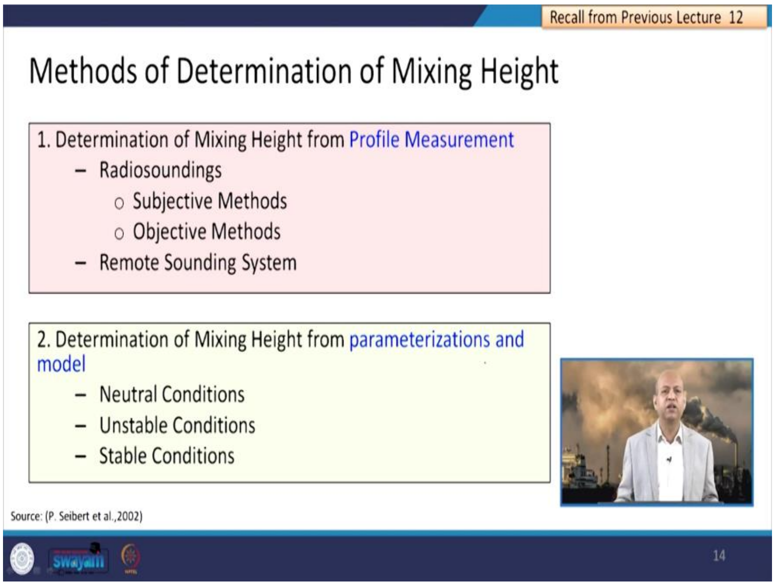

Well, so, methods of determining mixing depth are many or several, which you already know we have discussed in lecture number 12. So, those are like radio soundings, subjective method with the experts opinion, objective methods, remote sounding systems, then it can be determined by parameterization and modelling, like neutral conditions for unstable conditions or stable conditions. So, there are several ways to determine the maximum mixing height or depth.

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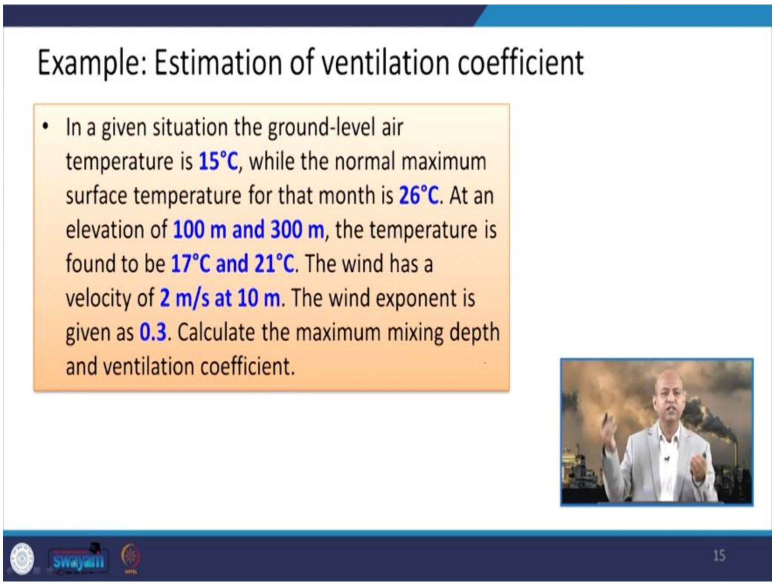

Well, now how to estimate this ventilation coefficient? So, let us go through this very small example for you, like in a given situation the ground level air temperature is 15 °C, it is given. While the normal maximum surface temperature for that month is 26 °C, because every day we are measuring. So, at certain day it was maximum 26 °C.

At an elevation of 100 meter, at the height of 100 meter and 300 meter the temperature is like 17 °C and 21 °C. Please note temperature is increasing with the height, so that you should know that this is inversion phenomena, otherwise temperature decreases with the height normally, when it is increasing then it is inversion. Well, the wind has a velocity of 2 meter per second at 10 meter height, that is the ground level we know.

Whenever we say, what is the wind velocity at the ground level? that means, we want to know the wind velocity or speed at the 10 meter height. The wind exponent is given as 0.3 which is used for determining the wind velocity at certain heights, because 10 meter it is given at the 10 meter. So, we want to measure at 100 meter, 300 meter then we will use this particular exponent. Then calculate the maximum mixing depth and ventilation coefficient with these parameters.

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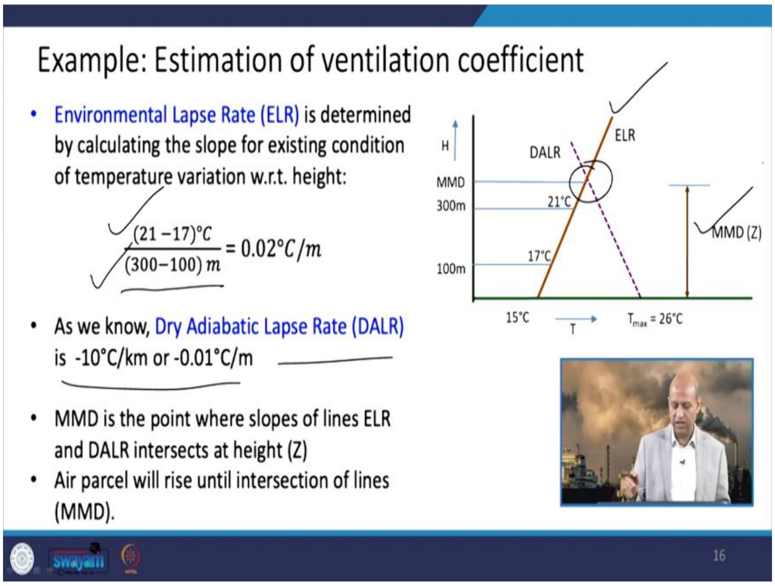

So, let us see. So, the environmental lapse rate first of all we need to calculate. So, this can be easily calculated by knowing the difference between the temperature, and knowing the difference between the elevation or between the height. So, this is 300 and minus 100 this is the height difference, then this is 21 minus 17 is the temperature difference. So, you can see here this is increasing temperature with height.

$\frac{(21-17)°C}{(300-100)\ m} = 0.02°C/m$

So, this is the inversion ELR this environmental lapse rate is showing the inversion phenomena. Now, dry adiabatic lapse rate we know this is 10 °C per kilometre decreasing, or you know 1 degree per 100 meter per 0.01 °C per meter. So, this we can draw, and it will intersect here. So, this is the maximum mixing depth or maximum mixing height, this Z you can say.

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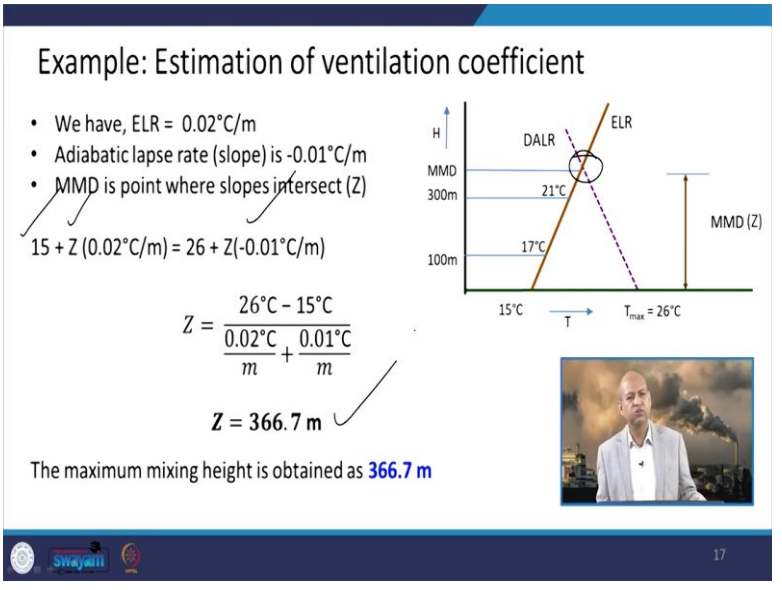

Well then, we want to know what is the height basically. So, the at that height, when these are intersecting up to that only the plume will go. Up to that air pollution will rise, and then it will hang over there. So, that you can calculate easily with this particular relationship, because the slope is given and the Z is there. So, Z will be used in both direction in both for both profiles, and you will, you can shift the Z value, and you can determine it, it is around 366.7 or 367 meter.

5 + Z (0.02°C/m) = 26 + Z(-0.01°C/m)

$$Z = \frac{26°C - 15°C}{\frac{0.02°C}{m} + \frac{0.01°C}{m}}$$

$$\boldsymbol{Z = 366.7\ \mathrm{m}}$$

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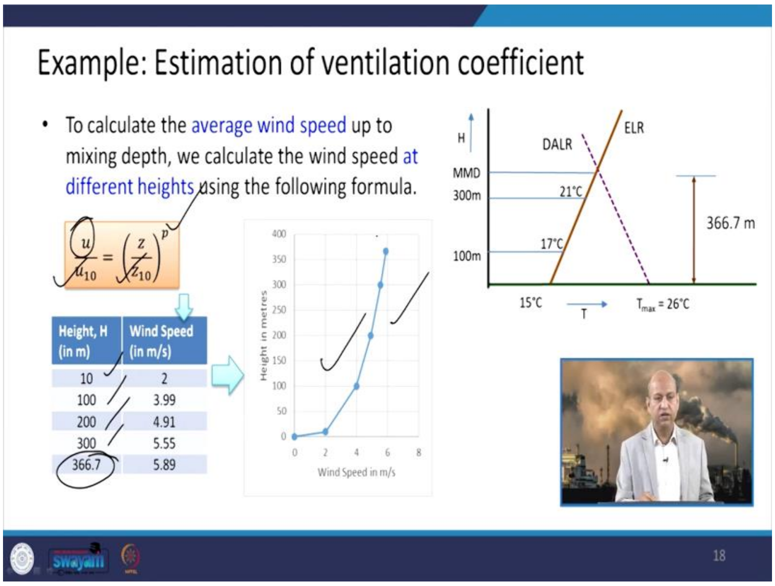

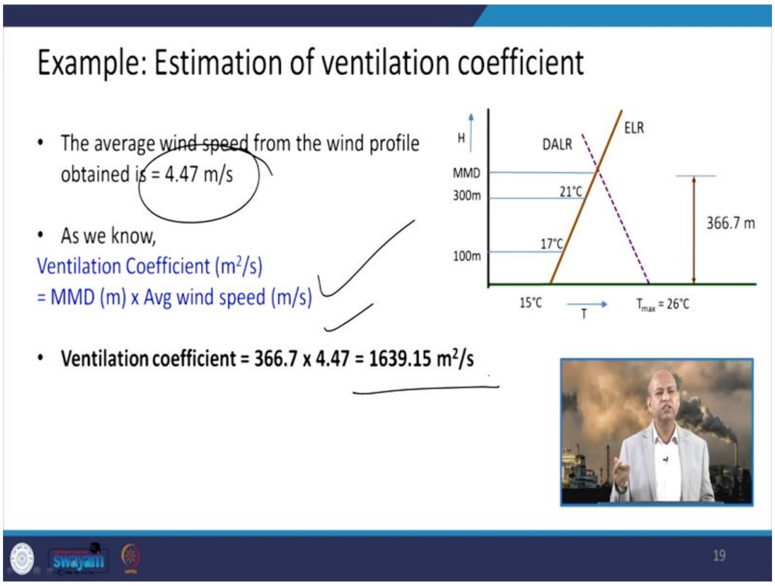

So, this is the maximum mixing depth. Well, now, we want to know the wind velocity at different heights. So, we know the wind velocity at 10 meter, and we know the coefficient that 0.3. So, p is known 0.3, we know that Z 10. And the u 10 is known. Now, we want to calculate u at different heights, and different heights are like 10, 100, 200, 300, or up to 366.7 which is the maximum mixing depth.

$$\frac{u}{u_{10}} = \left(\frac{z}{z_{10}}\right)^p$$

Height, H (in m)	Wind Speed (in m/s)
10	2
100	3.99
200	4.91
300	5.55
366.7	5.89

Ventilation Coefficient (m^2/s) *= MMD (m) x Avg wind speed (m/s)*

Ventilation coefficient = 366.7 x 4.47 = 1639.15 m^2/s

So, we have calculated this wind speed at several heights. And the average of this is to be calculated so that we can multiply it with the maximum mixing depth, and the average value is 4.47 meter per second. So, multiply it with the maximum mixing depth to estimate the ventilation coefficient. So, multiply and you get around 1639 square meter per second. So that is the value of the ventilation coefficient.

So, it will vary means depending upon the wind velocity and the maximum mixing depth. In the winter, generally mixing depth is low. So, it is low value of the coefficient, this ventilation coefficient and low potential of the dispersion.

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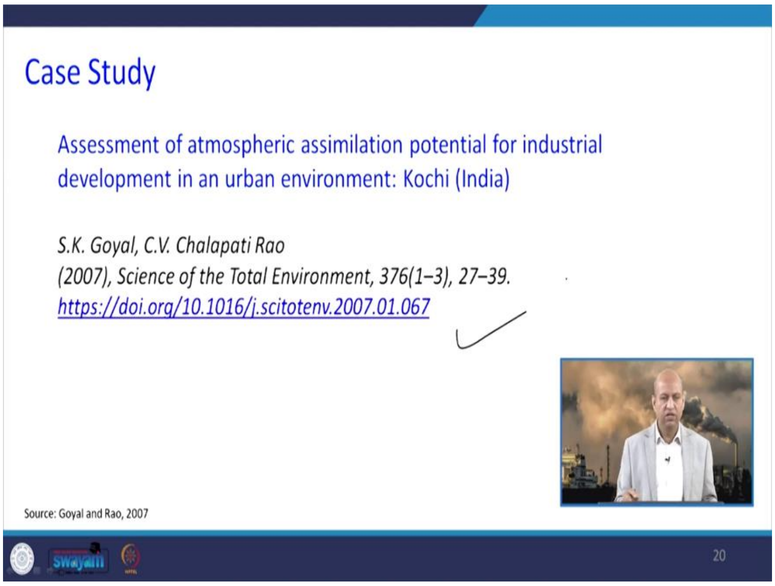

Now we come to the case study. So, this case study has been taken from research study or some fieldwork by S. K. Goyal, and C. V. Chalapati Rao from NEERI. And this is assessment of atmospheric assimilation potential for industrial development in an urban environment of the Kochi, India. So, we have taken this is the source reference you can go through we have taken only the few information just to give you an idea.

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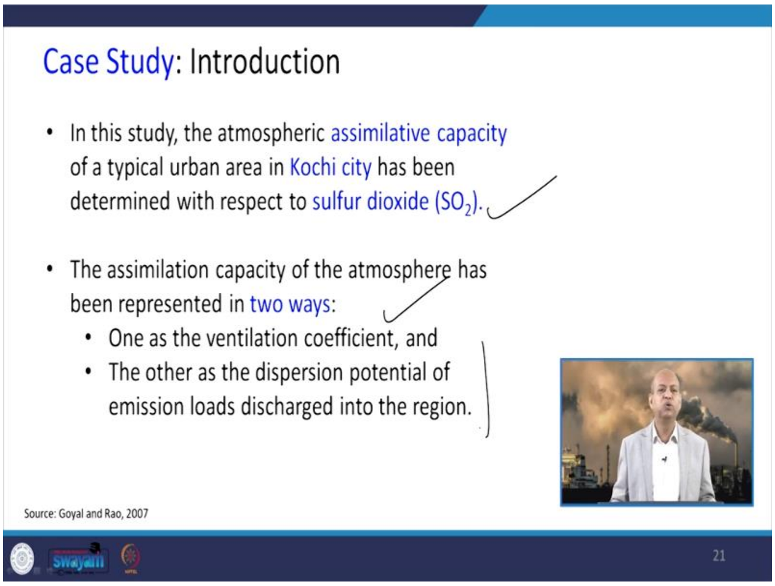

So, the introduction of the case study is that this is based on atmospheric assimilative capacity of a typical urban area which is in a Kochi city, this has been determined with respect to the sulphur dioxide, emission and dispersion of sulphur dioxide we will focus only on that particular pollutant. Then assimilation capacity of the atmosphere has been represented in two ways like ventilation coefficient, and then other dispersion potential of the emission load discharged into the region. So, we will use the dispersion model.

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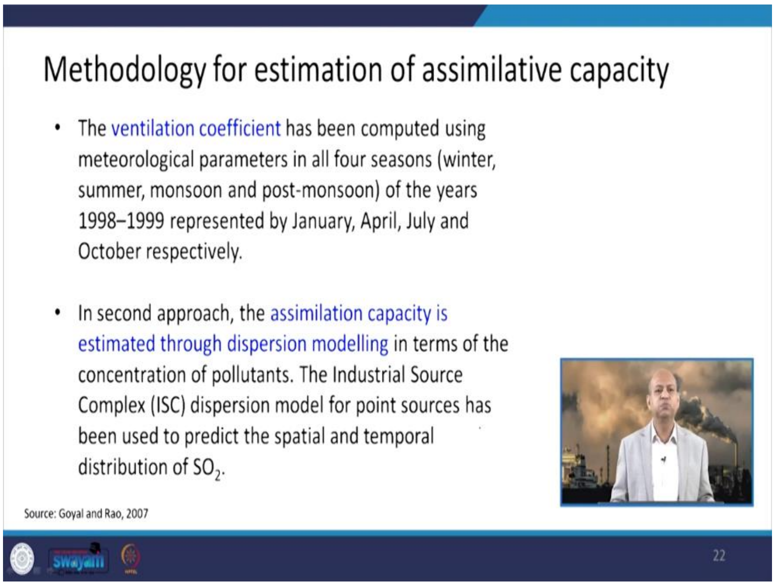

Well, the ventilation coefficient has been computed using metrological parameters for all seasons like winter, summer, monsoon, post monsoon those kind of for the year 1998 to 1999, and it has been represented by January, April, July, and October, respectively. Well, in second approach the assimilation capacity is estimated through dispersion modeling approach.

In terms of concentration of pollutant ambient air concentrations, and the Industrial Source Complex, ISC dispersion model for point source has been used which is of US EPA, which has been used to predict the spatial and temporal distribution of SO_2 through dispersion modelling.

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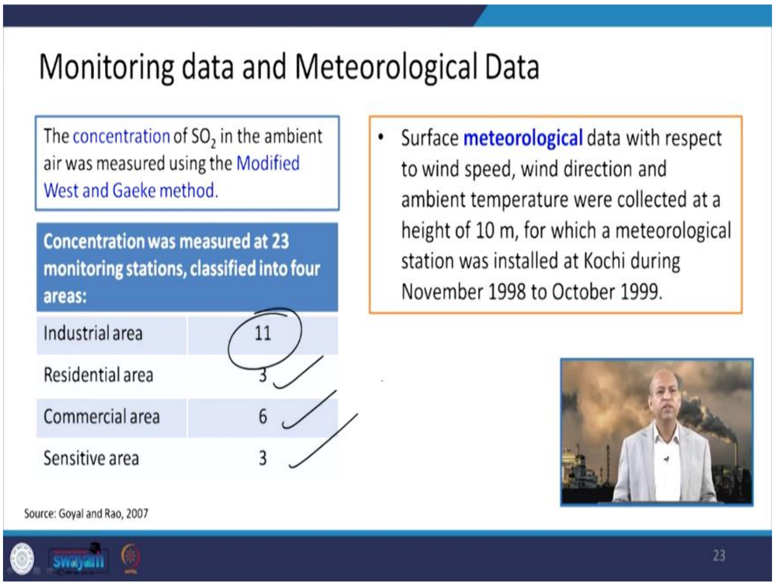

Then, we have to see how much data we need to know. So, there are representative monitoring sites like in industrial area, they have 11 monitoring sites and in residential area 3, commercial 6 sensitive areas 3. So, total 23 monitoring stations are there, where researchers have measured the surface metrological data with respect to wind speed, wind direction and the ambient temperatures.

These were collected at a height of 10 meter which is like ground level as I said, for which metrological station was installed at Kochi during November 1998 to October 1999. And the concentration of SO_2 in the ambient air was measured using the Modified West and Gaeke method, which is much popular for this SO_2 determination.

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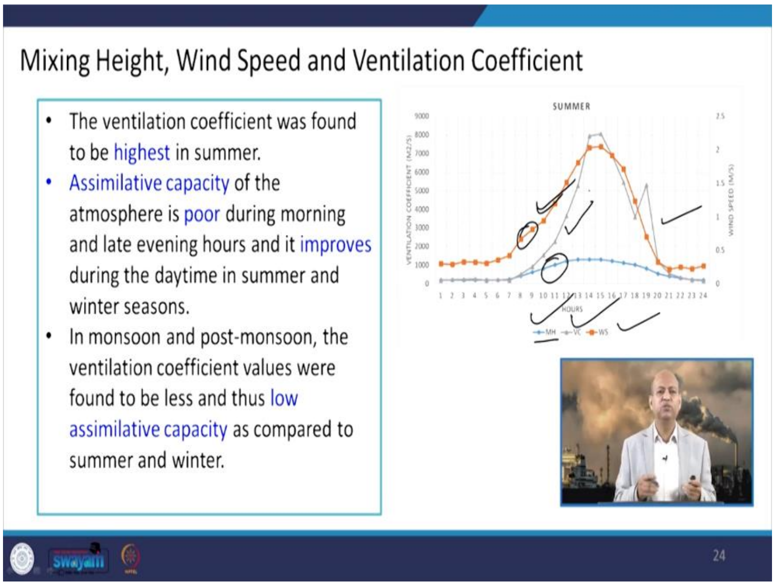

Well, now in study they have computed ventilation coefficient for different seasons for different points, we have given only this kind of sample representation. So, you can see for summer here has been calculated this mixing height, then ventilation coefficient, and wind speed. This is wind speed, this is the ventilation coefficient, and this is the mixing height and this is the ventilation coefficient.

So, the multiplication of this mixing height and this wind speed is the basically ventilation coefficient as you know. So, we have means, it has been drawn like that. Then the ventilation coefficient you know the comparison was made for different seasons and it was observed that, in summer it is the highest this ventilation coefficient which is also intuitively you can feel that in summer boundary layer height is more mixing height is more a lot of volume is there for dispersion.

So, that meant also wind flows with higher speeds, of course, it can vary from place to place as I said because in hilly areas, or plane, or coastal regions, it can be altogether different. And the assimilative capacity of the atmosphere is poor during the morning and late evening hours, when this mixing height becomes lower, and it improves during the daytime in summer and winter season when solar insolation is more so, mixing height increases.

In monsoon and post monsoon the ventilation coefficient values were found to be less, and thus low assimilative capacity was estimated in comparison to the summer and winter. So, these kind of assessment has been made in terms of ventilation coefficient.

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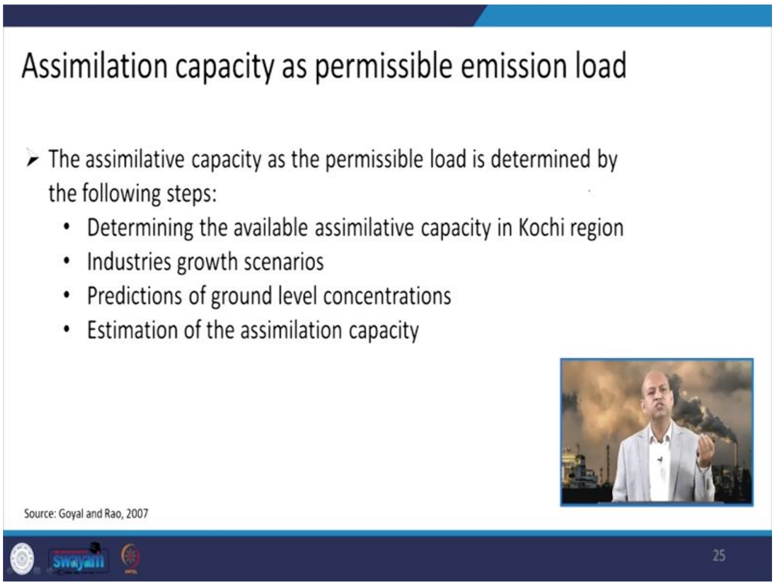

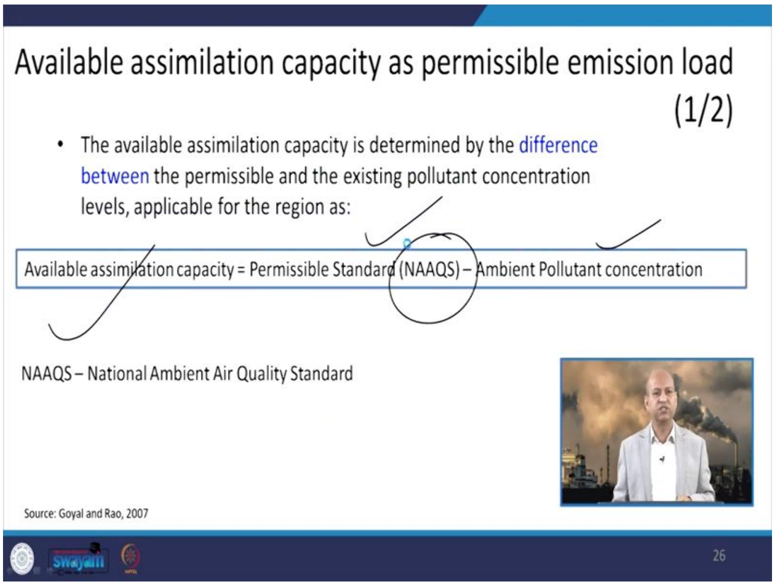

Now, we come to the assimilation capacity as permissible emission load, which is basically determined by available assimilative capacity you know in the Kochi region in terms of industries growth scenarios, then predictions of the ground level concentrations were made by using dispersion model, estimation of the assimilation capacity was made. So, how to differentiate between this available assimilation capacity, and permissible emission load.

So, because the permission emission load is calculated by indirectly by available assimilation capacity, and this available assimilation capacity is nothing but the permissible standard that is the national air quality standard based concentration, and difference between these standard and ambient pollutant concentration which has been background concentration is monitored in actual.

So, the difference means, if it is low than the ambient air quality standards, that means more pollution sources can be there and that will increase further but it has to be only up to that kind of quantity or amount that permissible standards that is national ambient air quality standards should not get violated. So, that gives the available assimilation capacity.

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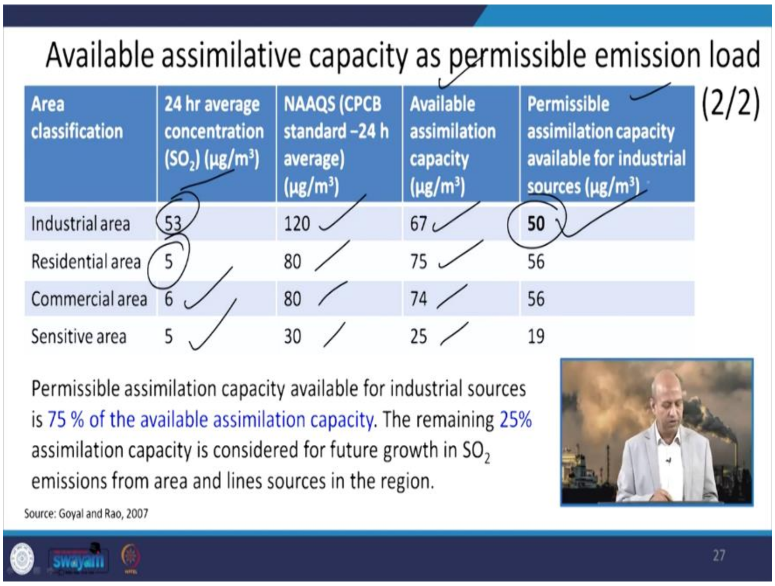

And then you know permissible assimilation capacity is basically taken as 75 percent of that available assimilation capacity. So, that is your kind of thumb rule, because that 25 percent is kept for considerations for future growth otherwise, if only one particular industrial development if they are using the complete capacity then there will not be scope for the future growth.

So, only 75 percent of the available assimilation capacity is used as the permissible assimilation capacity. And as I said, like industrial area 24 hour average concentration of SO_2 was measures like 53, in residential area it was 5, commercial area 6, sensitive area 5, 24 hours concentration. And the permissible limits by NAAQS is 120, 80, 80, 30. So, the difference between these two like 67, 75, 74, or 25 and the 75 percent of this 67 is 50 basically.

So, this has been because we are talking about industrial area, in terms of weather, some more industries can come some power plants can come refineries can come. So, this value has been taken because those scientists have considered only this particular industrial development related problem.

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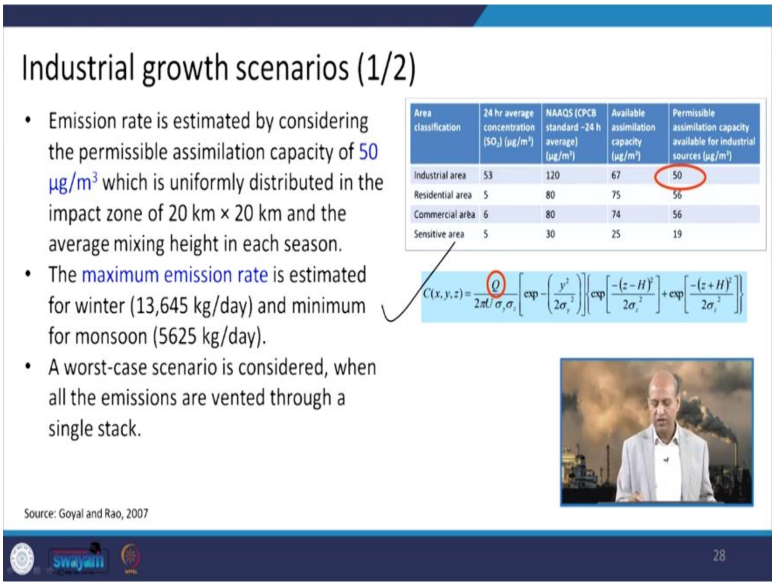

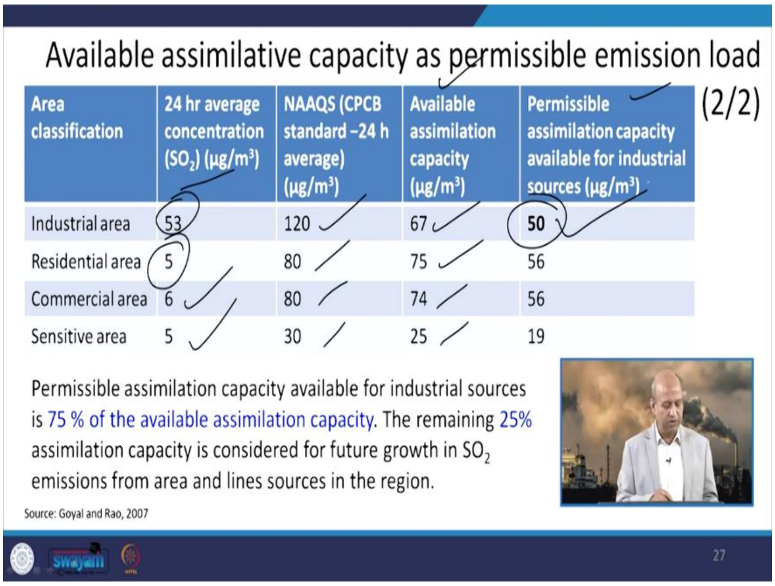

Well, so, the industrial growth scenario you can see this emission rate is estimated by considering the permissible assimilation capacity of 50 micrograms per cubic meter this much. And this is uniformly distributed in the impact zone of 20 x 20 kilometre that is known as the particular airshed you can say, and the maximum emission rate is estimated for winter like 13,645 kilogram per day and minimum for the monsoon that was 5625 kg per day.

And worst case scenario is considered when all the emissions are vented through a single stack. So, you can see here in industrial area related and this was the dispersion formula which the Gaussian dispersion equation which is used. So, the Q this is the emission rate which we need to determine, then there are other parameters which are like stack height and all those parameters you already know.

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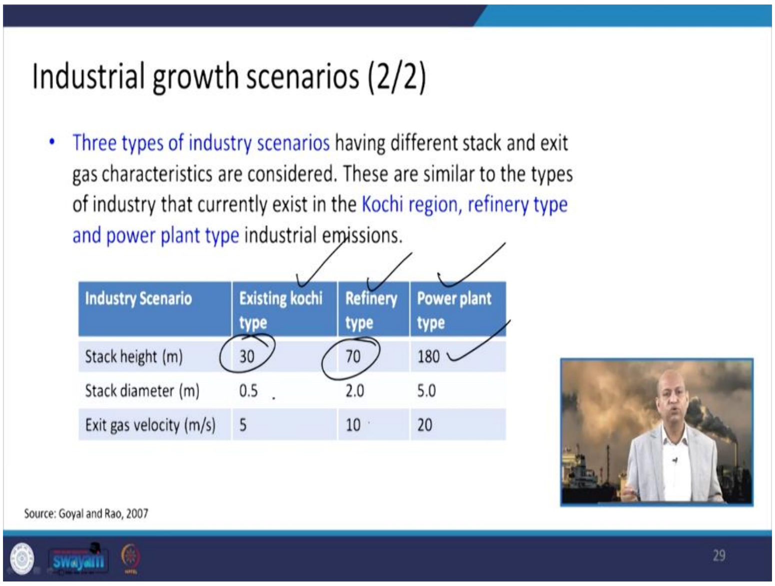

So, they stack height, you know like in industrial scenario stack height for existing Kochi around 30 meter only, and then refinery type scenario 70 meter up to 70 meter it can grow, and then power plant type 180 meter. So, three scenarios have been considered by the those researchers and they stack diameter are different for them, exit gas velocities also different and those velocities have to be used in that formula.

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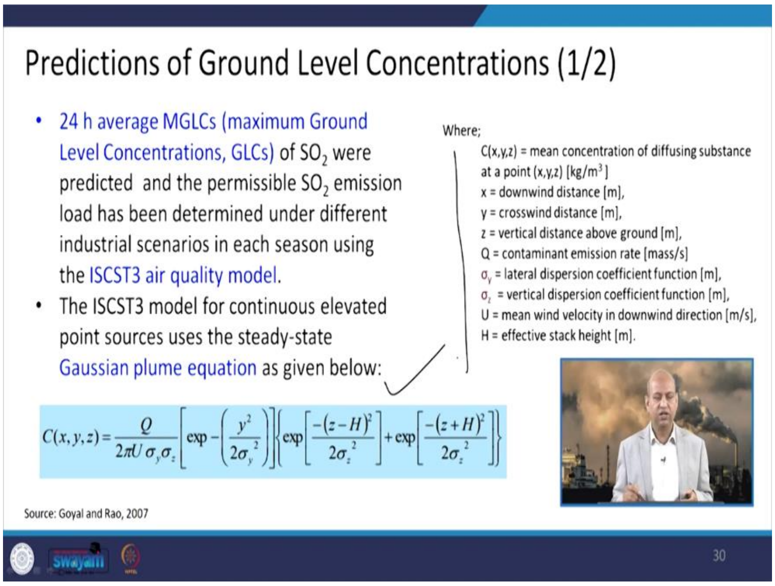

So, the 24 hours average maximum ground level concentration of SO_2 were predicted or estimated and the permissible SO_2 concentrations or emission load has been determined under different industrial scenarios using this ISCST3 air quality model of EPA, and this is the basic relationship of the Gaussian dispersion model which has been used and you know all these parameters which are to be used for calculation purpose.

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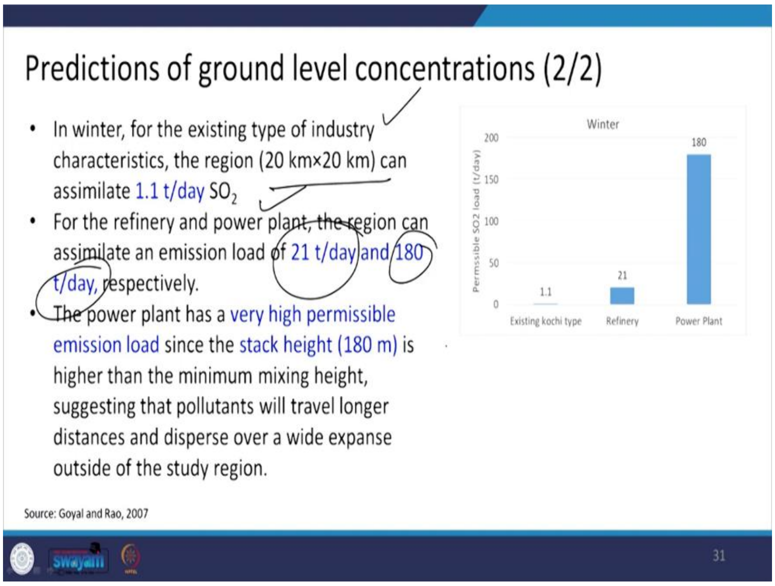

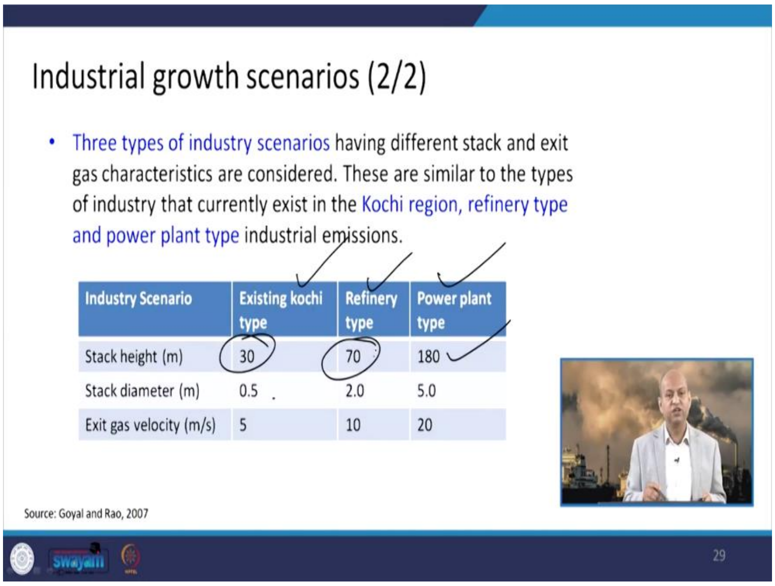

Well, so, it was estimated that in winter for existing type of industry characteristics the region 20 x 20 kilometre square can assimilate 1.1 tonne per day SO_2, that one scenario industry characteristic of existing means, existing scenario no change. If refineries to be taken, then it was estimated that around 21 tonne per day can be discharged, it is allowed more why, why is it so? Because of this is stack height. Because when stake height is more than 30, then it has chances of better dispersion or dilution.

Then in case of power plant 180 tonne per day was estimated that it can be allowed because in power plant you can see this 180 meter of the stack height is there. So, coincidentally that value is also about that do not get confused about that, but because of that stack height, lot of emission is allowed to be dispersed in the air because dilution will happen when it will come to the ground level because of this very large stack height.

So, the power plant has a very high permissible emission load because of this very large stack height 180 meter and this is higher than the minimum mixing height in comparison of all seasons. So, there are maximum, minimum mixing height. So, the minimum means the worst case scenario. So, beyond that it can easily disperse otherwise, it will take time for that disposition of the pollutants.

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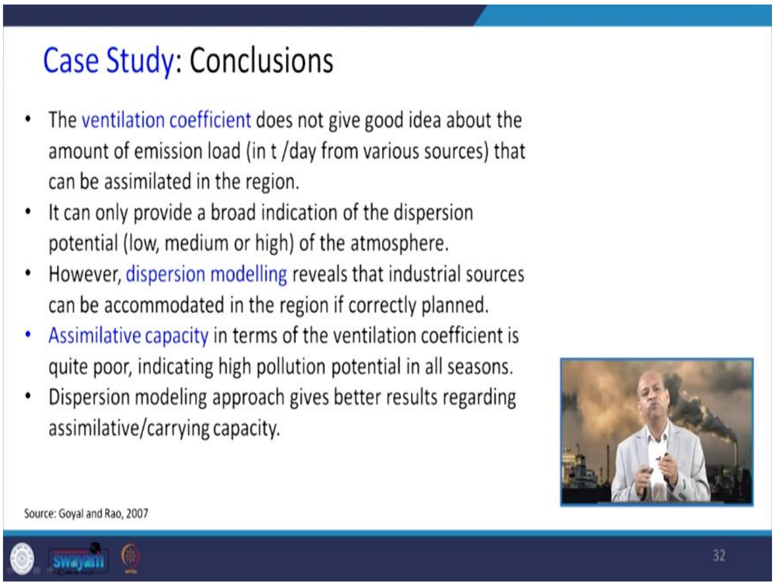

Well, in case studies conclusion we can say that the ventilation coefficient does not give good idea about the amount of emission load, it gives only the indication kind of that it is better dispersion possibility or lower possibility, it can only provide a broad indication of the dispersion of the pollutants low, medium, high like that, but does not give good quantitative assessment.

But dispersion modeling reveals the industrial sources can be accommodated in the region if correctly planned, means this gives the real values, whether which kind of industries can be planned and how much it can allow the assimilative capacity to come through. Then assimilative capacity in terms of the ventilation coefficient is quite poor indicating high pollution potential in all seasons.

And dispersion modeling approach gives better results regarding assimilative or carrying capacity. So, means this this is very interesting study thanks to Dr. Goyal and his team, that you know the variation or the comparison of ventilation coefficient and this pollution dispersion modeling related approach has given clear cut demarcation that dispersion modeling related approach is much better.

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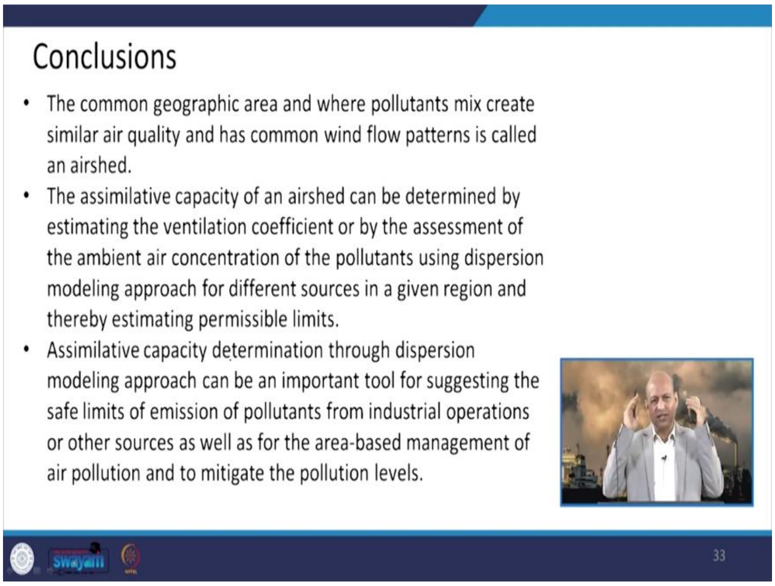

So, overall conclusion can be taken from this list, that the common geographical area where pollutants mix, create similar air quality kind of profiles had common wind flow patterns, they are called the airshed as we have seen airshed, because the topic is related to assimilative capacity of the airshed or carrying capacity of the airshed. So, we should know what is the airshed?

The assimilative capacity of an airshed can be determined by estimating the ventilation coefficient or by the assessment of the ambient air concentration of the pollutants using dispersion modeling approach for different sources in a given region and thereby estimating permissible limits as we have seen in Dr. Goyal's study.

Assimilative capacity determination through dispersion modeling approach can be an important tool for suggesting the safe limits of emission of pollutants from industrial operations or you know for the say other operations also like power plants etc, and other sources as well for the area based management of air pollution and to mitigate the pollution level.

So, this is all for today. I hope you now get clarity about what is the carrying capacity or assimilative capacity of an airshed.

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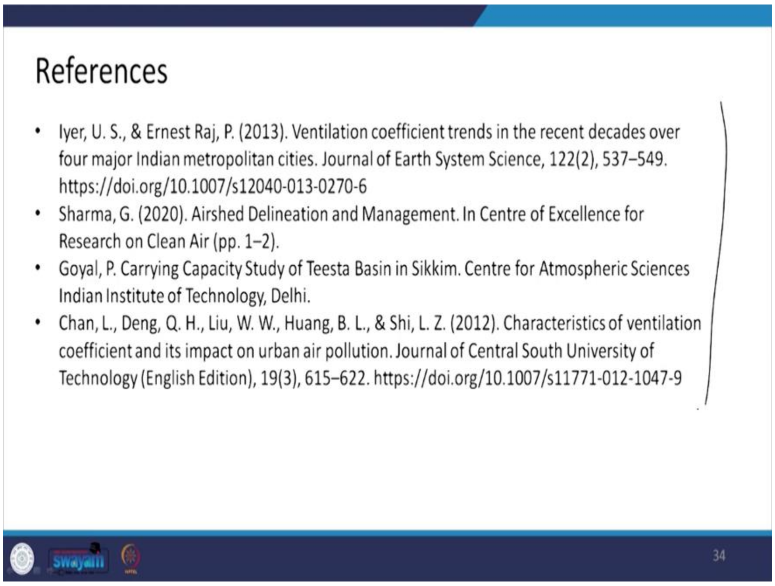

Now, these are the references for your additional information which you can go through at the free time. So, this is all for today. Thank you for your kind attention. See you in the next lecture. Thanks again.