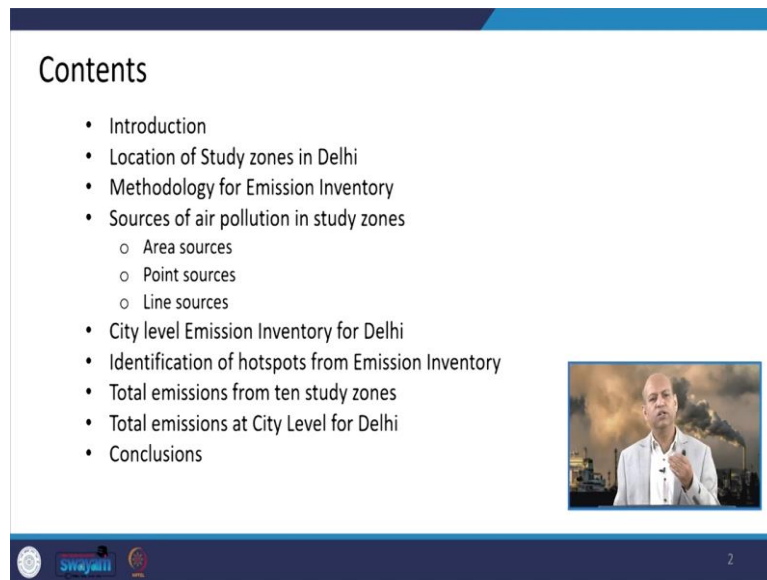


Air Pollution and Control
Professor Bhola Ram Gurjar
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture 26
Emission Inventory: Case Study


Hello friends. So, far we have discussed recently regarding how to develop emission inventory for different source categories like residential, commercial, for transportation sector, industrial areas, all those things. So, today we will discuss one case study, so that how to apply those theoretical relationships which are used for developing of emission inventory, how these emission inventories are constructed and what are their applications or what kind of lessons we derive from those emission inventories.


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Contents

- Introduction
- Location of Study zones in Delhi
- Methodology for Emission Inventory
- Sources of air pollution in study zones
 - Area sources
 - Point sources
 - Line sources
- City level Emission Inventory for Delhi
- Identification of hotspots from Emission Inventory
- Total emissions from ten study zones
- Total emissions at City Level for Delhi
- Conclusions





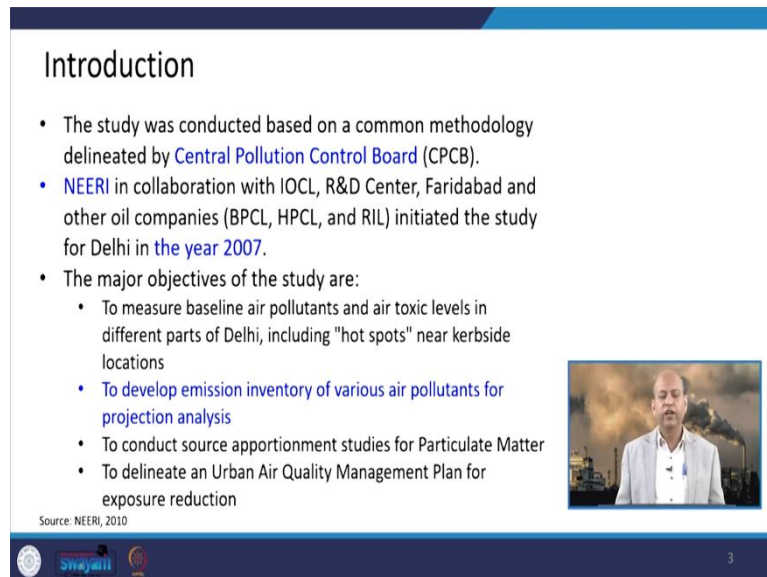
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So, today's lecture will have this particular small introduction about the case study where we have taken it up. Then what is the location of the study in different zones in Delhi which is the focus area of this particular study and the methodology which has been used for development of this case study of emission inventory, then different sources which have been, incorporated in this particular study like area sources, point sources or line sources related emissions.

Then city level emission inventory for Delhi because the case studies focused on certain number of zones study zones are there 10 studies zones are there we will see, but then it has been extrapolated to estimate the emissions from the entire Delhi city. So, that methodology also we will see into. Then, we will see how the identification of hotspots have been done by this emission inventory, where lot of emissions are coming from, then the total emissions from

10 study zones as well as total emissions from the city level of the Delhi and then we will conclude.

(Refer Slide Time: 02:12)



The slide is titled "Introduction" and contains the following text:

- The study was conducted based on a common methodology delineated by [Central Pollution Control Board \(CPCB\)](#).
- [NEERI](#) in collaboration with IOCL, R&D Center, Faridabad and other oil companies (BPCL, HPCL, and RIL) initiated the study for Delhi in [the year 2007](#).
- The major objectives of the study are:
 - To measure baseline air pollutants and air toxic levels in different parts of Delhi, including "hot spots" near kerbside locations
 - To develop [emission inventory of various air pollutants for projection analysis](#)
 - To conduct source apportionment studies for Particulate Matter
 - To delineate an Urban Air Quality Management Plan for exposure reduction

Source: NEERI, 2010

The slide also features a small video inset on the right side showing a man in a white shirt speaking, and a footer with logos for Swayam and NEERI, and the number 3.

So, basically this study was conducted based on a common methodology, which was delineated by Central Pollution Control Board and NEERI in collaboration with the Indian Oil Corporation Limited and R & D Centre Faridabad of that IOCL and other oil companies like BPCL, HPCL, RIL. And they initiated this study for Delhi in the year 2007. And it was published in 2010.

Well the major objectives of this study were like to measure the baseline air pollutants and air toxic levels in different parts of Delhi city, that is mega city Delhi you can say including the hotspots, where a lot of emissions are coming from near like curb side of the roads etc, then to develop emission inventory for various air pollutants for projection analysis.


So, that we can project and analyse for the entire Delhi city and then to conduct source apportionment studies for particulate matter, which is not part of today's case study we have focused only in emission inventory development. Then to delineate an urban air quality management plan for exposure reduction, that is also not part of that, but we will touch like, what is the lessons we can learn from these results, which are of this particular emission inventory.

(Refer Slide Time: 03:25)

Introduction

- Emission inventory incorporating different sources of air pollution has been prepared at two scales, (i) one for the ten Study Zones of 2 km x 2 km around the air quality monitoring sites and (ii) then this emission inventory was used to estimate/extrapolate total emissions for the whole of the city.
- Emission inventories of industrial (point) source, area and vehicular (line) sources were prepared.
- The secondary data on the quantity and composition of these sources in different zones of Delhi were collected from various sources. Primary data were collected through questionnaires and specific surveys

Source: NEERI, 2010



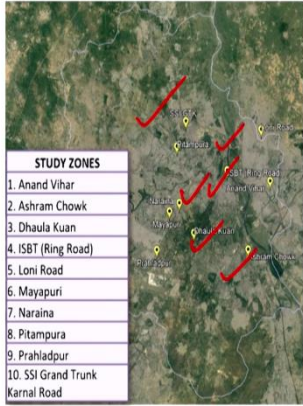
4

So, this particular emission inventory has 10 zones and it has got two kind of distinct scales like one for the 10 study zones of 2 x 2-kilometre, 2 kilometres x 2-kilometre around the air quality monitoring sites which are already functioning, and then the emission inventory which was developed for these time zones, which were extrapolated and total emissions for the whole city of Delhi has been estimated. So, two parts are there basically.

Then what are different sources which have been incorporated in the emission inventory or like point sources which are basically industrial sources like stack emissions, then area sources like domestic and commercial areas etc. Then vehicular sources that is line source, so all point line area source have been considered and there have been, primary data collection also based on questionnaire survey and other specific surveys plus secondary data have been taken from various kinds of published reports and other, sources of data.

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Location of study zones in Delhi



- Emission inventory for various sources of air pollution has been prepared for the **Ten Study Zones** of 2 km x 2 km size around the air quality monitoring site.
- Emission inventory has been prepared in terms of five major pollutants, viz. **PM₁₀, SO₂, NO_x, CO and HC**.

Map showing the study zones with location in Delhi

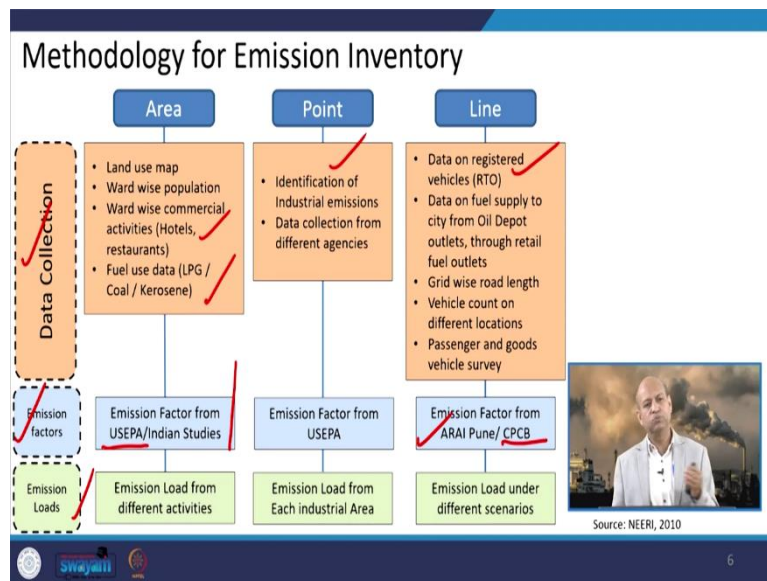
Source: NEERI, 2010 Image: Google Earth Map

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Well, so these are the locations of study zones like Anand Vihar, Ashram Chowk. So, in this particular map it is shown like a small-scale industry of Grand Trunk Karnal Road, then this is Pitampura and Naraina, then ISBT Ring Road, Ashram Chowk, Dhaula kuan. So, all these kinds of these 10 locations of the 10 study zones are depicted in this particular map which you can see and each zone has like 2 kilometre x 2 kilometre size.

So, that the detailed study can be carried out with limited resources and then we can extrapolate, because these are the kind of representative zones you can see. And it has been prepared this inventory has been prepared in terms of 5 major pollutants, which are like PM₁₀ that is a particulate matter of the size 10 micrometre or less and then sulphur dioxide, oxides of nitrogen NO₂ etc, then carbon monoxide and hydrocarbons HC.

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So, these are the methodologies for emission inventory for every kind of category like area source point source or line source. So, basically first of all, data collection is there for any kind of activity basically, you must remember for emission inventory development from bottom to up approach, we go first of all for data collection, we collect the data which are needed for any kind of activity which is responsible for emissions of your pollutants.

So, the activity data is important whether area source or point source or line source, activity data you have to collect and then the those total fuel burning or those kind of estimations are to be done, then emission factors are there for each kind of activity. So, those are clubbed and then total emissions are estimated that is the particular basic thing which every kind of emission inventory incorporates.

So, data collection then emission factors also, the specific emission factors means, the localised or the activity based emission factor must be there. If there are no indigenous emission factors then we have to rely upon some literature, some other like EPA or WHO reports also contained from different countries. So, whatever economies are similar to ours that we can borrow and we can use in the absence of the indigenous emission factors, then the emission loads are estimated.

So, like for example, for area source first of all we must know the land use, what kind of land use is there in that area, what are activities of domestic nature commercial nature etc. Then hotels, restaurants or fuel use data, how much LPG or coal kerosene are being burned all those things, then emission factors are to be taken from Indian studies, first of all and otherwise like

USEPA in this particular study, they have taken the emission factors from Indian studies and wherever those emission factors were not available.

So, they have, based upon USEPA United States Environmental Protection Agency's emission factors. So, that thing is common in all these for line sources like vehicular categories. So, first of all we need to collect data from like RTO office, where we can get different categories of vehicles numbers and age etc.


So, all those data then emission factors from our Pune based institute, which is automobile related institute and then CPCB related emission factors are also there, for point source, we need to identify how much industries are there or power plants are there in this study zones, which have been considered there are no power plants, but beyond that power plants are there so, they have also been incorporated.

(Refer Slide Time: 08:30)

Sources of air pollution in study zones

Source Category	Types of sources
Area Sources	Domestic cooking & heating
	Burning of waste/derived fuels
	Bakeries
	Crematoria
	Hotels & Restaurants
	Open eat outs
	Open burning (refuse/biomass/ tyre etc. burning)
	Paved & unpaved roads, Construction/Demolition/
	Alteration activities for buildings, roads, flyovers
	Waste Incinerators
DG Sets	
Point Sources	Large scale industries
	Medium scale industries
	Small scale industries
Line Sources	2 Wheelers (Scooters, Motor Cycles, Mopeds)
	3 Wheelers (CNG)
	4 Wheelers (Gasoline, Diesel, CNG)
	LCVs (Light Commercial Vehicles)
	Trucks (Trucks, min-trucks, multi-axle trucks)
	Buses (Diesel, CNG)

Air pollution sources in this study are broadly categorized as **area** (domestic and fugitive combustion type emission sources), industrial **(point)** sources and vehicular **(line)** sources.



Source: NEERI, 2010


So, if we go by sources like different sources like area sources, so these like domestic cooking or heating then burning of the waste, derived, waste derived fuels like those residue etc, then bakeries or hotels, restaurants etc have been incorporated in point source, large scale industries, medium scale industries or smaller scale industries. Those related information we have missed in this study has been taken. Then in line source like 2 wheeler, 4 wheeler, 3 wheeler and then with fuel they are being run by like CNG or these gasoline that is petrol or diesel, all those kind of related different categories have been taken up.

(Refer Slide Time: 09:18)


Area Source

Data Collection


- Activity Data on area source activities were collected from various Government and Non-Government departments/agencies.
- Primary data on demographic profile and fuel consumption in various activities/ sources were obtained in the prescribed format through primary survey in the study zones around each of the AQM stations.
- The emissions from various activities were estimated by applying the activity data and emission factors compiled by CPCB.




Cooking



Waste burning



DG sets




Source: NEERI, 2010; Image: <https://qz.com/>, <https://www.intelligentliving.co/>,

Area Source

Data Compilation and Analysis

AQM Location	Population	Slum population	Sources								
			Hotels & Restaurants	Dhabas & Sweet Shops	Bakeries	Crematoria	Open Burning	Gen sets	Medical Incinerator	Locomotive	
Ashram Chowk	62508	4495	14	-	-	-	300 kg	1236	-	3	
ISBT	27481	-	7	-	-	-	-	927	-	-	
Dhaura Kuan	20623	-	10	-	-	-	-	985	-	-	
Mayapuri	60373	-	12	9	1	-	-	427	-	-	
Anand vihar	25416	-	14	-	-	-	250 kg	129	-	-	
Loni Road	117317	-	9	-	-	-	-	276	-	-	
Pitampura	95472	-	19	-	2	-	-	860	-	-	
SSI-GTK	20781	33020	-	-	-	-	-	513	-	14	
Naraina	43464	30817	14	4	1	-	-	875	-	38	
Prahladpur	28817	-	-	6	-	-	-	407	-	-	

The table provides the information of the number of area sources contributing to air pollution in each location.



Source: NEERI, 2010

Then so, data collection as I said that activity data have been collected with primary sources like survey based and then the secondary sources from different kinds of reports or publications from government as well as non-government organisations. So, this kind of data compilation and analysis was established like metrics has been there, like air quality monitoring locations for Ashram Chowk, ISBT, Dhaura Kuan etc.

Then how much population is there in that particular zone, how much slum population is there because their burning of fuel is distinct than the other population. So, that has been segregated hotels, restaurants then these dhabas or, the sweet shops, bakeries, they also emit lot of emissions because of fuel burning in their activities. Open burning then Gensets because

whenever electricity is not there then generators run. So, diesel is used and lot of emissions are there medical waste incinerators, wherever.

So, in these particular zones there were not neither medical waste in incinerators or neither there were any crematoria's. So, those kinds of emissions were not there, then locomotives were there, a few locations like Ashram Chowk and the Naraina etc. So, those have been also considered.


(Refer Slide Time: 10:38)

Area Source

Data Analysis

- Hotels/ restaurants and Dhabas are situated in the study zones of almost all the sites.
- No crematorium was observed near any one of the AQM locations. No medical waste incinerator and solid waste disposal facility was found near any one of the sites.
- During the period of power cuts, generator sets are operated in residential co-operative societies as well as commercial shops. Various capacities of generators sets are used depending on the requirement of power.
- Open burning was observed during survey at Ashram Chowk and Anand Vihar.
- Diesel locomotives are plying for carrying goods near Ashram Chowk, Naraina and Anand Vihar locations.

Source: NEERI, 2010



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Well, so as I said, like hotels or open burning diesel locomotives, which were plying to carry goods in between Ashram Chowk, Naraina, Anand Vihar locations they have been also considered.


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Area Source

Area Source: Emission factors

- CPCB recommended /available emission factors from various studies/reports for various types of fuels. Combustion processes were used for estimation of emission load.
- Since, emission factors were not provided for LPG in domestic sector, the emission factors reported in EPA study (2000) were used for estimating emissions.
- In case of any particular pollutant for which emission factor is not available, EPA's AP-42 (2000) emission factors have been used for calculations.

Source: NEERI, 2010



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Well, so emission factors as I said that CPCB Central Pollution Control Board has recommended the emission factors for various activities. So, whatever emission factors were available for from CPCB, then they those have been taken. Otherwise, this EPA's AP-42 2000 emission factors compilation is there for different sources and activity, those have been taken wherever, indigenous data are not available for emission factors.

(Refer Slide Time: 11:18)

The slide is titled "Area Source: Emission Load Estimation (1/2)" and is part of a presentation on "Area Source". It contains a numbered list of five steps:

1. Estimation of population in each 2 km x 2 km study zone
2. Estimation of slum population in each 2 km x 2 km study zone
3. Estimation of fuel consumption in different types of source categories in each 2 km x 2 km study zone
4. Comparison of fuel consumption in summer and winter seasons
5. Identification of land use based on Eicher Map of Delhi City, available in 500 m x 500 m grid size

A small video inset in the bottom right corner shows a man speaking. The slide also includes the source "Source: NEERI, 2010" and logos for "Swayam" and "12" in the footer.


Well, so area sources if we consider first of all, then the estimation of population in each 2 kilometre x 2 kilometre study area was carried out then the slum population and estimation of fuel consumption or comparison of the fuel consumption in summer, so season seasonal variation or winter seasons that has been also taken up. Identification of the land use pattern so, that it can give different information like Eicher map was used in nowadays, sophisticated maps are there, but in 2007 they used the Eicher map of the Delhi city for the land use patterns.

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Area Source

Area Source: Emission Load Estimation (2/2)

6. Estimation of emission load in terms of five major pollutants, viz. PM₁₀, SO₂, NO_x, CO, and HC in each of the 2 km x 2 km study zones using collected data on each category of source and applicable emission factors.
7. Estimation of emission load from open burning (based on quantity estimation/ visual observations).
8. Estimation of PM₁₀ load due to construction activities in each study zone.
9. Estimation of percent emission contribution (in terms of PM₁₀, SO₂, NO_x, CO, and HC) for each source category in each of the study zones.
10. Preparation of overall average fuel consumption and emission scenario based on the data collected for the ten 2 km x 2 km study zones



Source: NEERI, 2010


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Well, then estimation of emission load in terms of 5 major pollutants like PM₁₀ as I said earlier or SO₂, NO_x, CO and HC. So, in within that 2 kilometre by 2 kilometre estimations have been made, and this percent emission contribution for each source category has also been estimated when you have the total and from different sources. So, you can easily calculate how much percentage coming from different sources or how much percentage of a particular pollutant is coming from a particular source. So, those kinds of things we can easily play. So, that has been given in this particular report.


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Area Source


Total Emissions from Area Sources

- Among all the study zones, highest area source emissions in terms of all the five pollutants are estimated at SSI-GTK and Naraina while minimum area source emissions are estimated at Dhaula Kuan.

Pollutants	Min (kg/day)	Location	Max (Kg/day)	Location
PM ₁₀	4.9	Dhaula Kuan	1171.2	SSI GTK
SO ₂	3.4	Dhaula Kuan	36.8	Naraina
NO _x	36	Prahladpur	327.4	Anand Vihar
CO	48.1	Dhaula Kuan	1580.3	SSI GTK
HC	50.6	Dhaula Kuan	535.5	Loni Road



Source: NEERI, 2010


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Well, so if we talk about the total emissions from area sources in those particular zones, so you can see like there are these emissions of CO carbon monoxide. So, from this small-scale

industrial area of Grand Trunk Road and the Naraina they have been much more responsible for emissions of CO, carbon monoxide and these hydrocarbons are also there.

So, if we see the location wise like PM₁₀, the minimum emissions are from Dhaula Kuan basically Dhaula Kuan and Prahladpur are responsible for minimum emissions of different pollutants and pollutant wise like PM₁₀ maximum emission was from the smallest scale industries in Grand Trunk Karnal Road and the NO_x emissions were more in, Anand Vihar and the CO emissions were again from the small-scale industries Grand Trunk Road. So, that way different, locations have been identified where maximum emissions are there, and where minimum emissions are there.

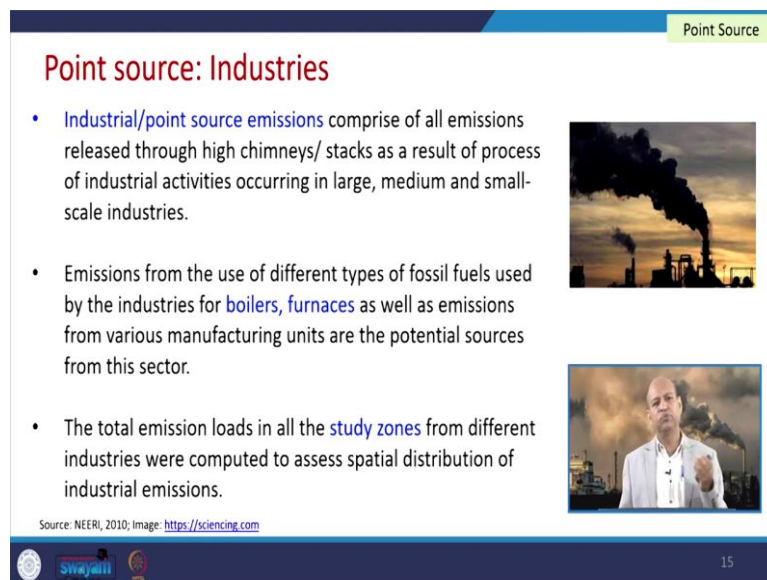
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Point Source

Point source: Industries

- Industrial/point source emissions comprise of all emissions released through high chimneys/ stacks as a result of process of industrial activities occurring in large, medium and small-scale industries.
- Emissions from the use of different types of fossil fuels used by the industries for boilers, furnaces as well as emissions from various manufacturing units are the potential sources from this sector.
- The total emission loads in all the study zones from different industries were computed to assess spatial distribution of industrial emissions.

Source: NEERI, 2010; Image: <https://sciencing.com>



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Well for point sources like industries, so the industrial point sources for that particular, survey was conducted and stacks were counted how many chimneys are the stacks are there which are emitting those air pollutants, well boilers, furnaces related, data were collected, and then total emission loads were estimated by those using those formula which are used for stack emissions.


(Refer Slide Time: 13:55)

Point Source

Point source: Data Collection

- According to National Council of Applied Economic Research (NCAER) Industrial Census Report, 2002, there are 17,112 polluting industries in Delhi. Out of which, 2266 units are of air polluting nature (DPCC data).
- Large-scale industries are power plants based on coal and gas. Out of five plants, three are located near IP Estate and other two are near Pragati Maidan and Badarpur area.
- The medium scale industries are concentrated in Lawrence road Industrial area.

Industrial Category	Air Pollution Industries
Large scale - Power Plants	5
Medium scale	9
Small scale	2252



Source: NEERI, 2010

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Well then in the data collection has been done from National Council of Applied Economic Research related reports 2002 There are like, in 2002, this was 17,112 polluting industries. So, that way those data have been there, and these 2,266 units are polluting in nature from DPCC data that was taken out of which, so segregation has been there, large scale, medium scale small scale, small scale are like 2252 industries are there.

And then, in large scale industries power plants were considered basically there are like 5 plants, but there they were not in those study zones. And these three are located in IP estate and then the two are near Pragati Maidan and Badarpur area areas. So, those have also been considered, then medium scale industries, concentrated on Lawrence road industry areas, so those who have been also considered in this study.

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Point Source

Point source: Data Collection

- Of the total 2252 small scale industries, 723 units lie in the **four** out of ten 2 km x 2 km study zones. The information available on the small-scale industries were categorized with respect to nature of product & byproduct, viz. power, metallurgical, engineering, chemicals, textiles and food/beverages etc.

Industrial Category	Air Pollution Industries
Large scale - Power Plants	5
Medium scale	9
Small scale	2252

Four study zones (723 units)

1. Mayapuri (235)
2. Anand Vihar (105)
3. Naraina (174)
4. SSI GTK (209)

Source: NEERI, 2010

Well, when we talk about these small scale industries and if we see where they are located, so Mayapuri, Anand Vihar, Naraina and these small scale industries Grand Trunk Karnal Road is there. So, engineering studies like if we zone wise if we see which kind of industries are there which are responsible for various kind of emissions. So, the engineering chemical metallurgical pharmaceutical, so those kind of industries are there and then other industries other kind of which are not in this particular category.

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Point Source

Emissions from industrial sources

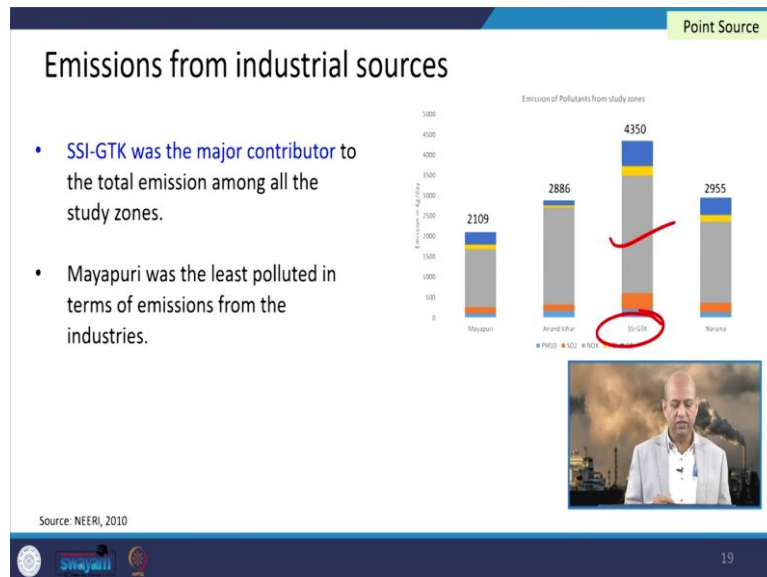
- Emission loads were estimated by using **CPCB recommended emission factors** wherever they are available and in other cases EPA's **AP-42 emission factors** were used.
- It was observed that the overall emissions from **Metallurgical** (2297.3 kg/day) and **Engineering** industries (2291.3 kg/day) were found to be the highest.
- Food** (400 kg/day) and **Pharmaceutical** (535.2 kg/day) industries were least polluting.

Source: NEERI, 2010

Well, when we talk about like engineering industries are there emissions from different small-scale industries. So, the engineering industries metallurgical industries are responsible for maximum emissions you can see and NOx emissions are coming lot of from all these kinds of

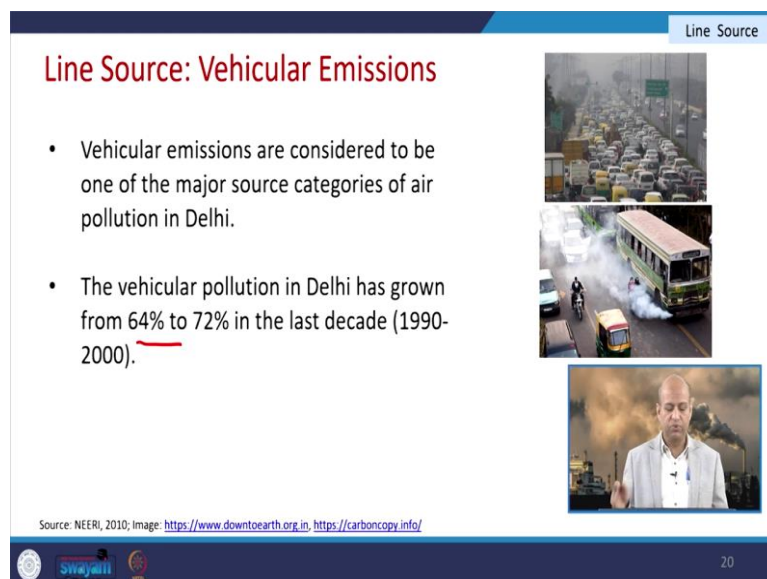
industries. So, you can see the dominating emissions are NO_x from these particular industries in a very large quantity.

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Well, if you see these from industrial sources again pollutants like PM₁₀ or sulphur dioxide, NO_x etc. So, again NO_x is dominating and then CO is also there. So, you can see the difference between different kind of areas like this small-scale industrial area of Grand Trunk Karnal Road is the major contributor, if we compare with other industrial areas. Mayapuri is the least polluting area in that sense.

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Well, now if we talk about like line source emissions, that is vehicular emissions, so, we have considered like area source point source and now, line source. So, line source basically

vehicular emissions you can think of, so these are responsible for a large amount of like CO NOx etc and they have, vehicular pollution has increased from 64 percent to 72 percent in the last decades, so lot of growth has been there.

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Line Source

Approach/Methodology for estimation of vehicular emission

1/2

Primary data on traffic counts collected on each road in each of the study zones has been analyzed with respect to the following:

1. Total daily traffic volume on major roads (arterial/ring roads)
2. Peak hour traffic composition as fast moving vehicles, buses, goods vehicles and slow moving vehicles
3. Comparison of peak hour traffic composition on working and non-working days (on the roads nearest to the AQM Sites)
4. Estimation of traffic composition on different types of roads (arterial, main and feeder roads) in each 2 km x 2 km study zone
5. Estimation of total vehicle kilometer travel (VKT) in each study zone based on traffic data and road length. Length of different types of road categories (arterial roads, main roads and feeder roads) has been estimated from Eicher Map of Delhi City, available in 500 m x 500 m grid size



Source: NEERI, 2010

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Well, so, far these calculating estimates or estimating the emissions from vehicular category. So, primary data of the traffic counts have been collected from RTO office, then different kinds of category like how much how many, vehicles are there are 4-wheeler category 2-wheeler within 2-wheeler 2 stroke engine, 4 stroke engine, so those kinds of categorization have been there and those values have been taken into.


(Refer Slide Time: 17:19)

Line Source

Approach/Methodology for estimation of vehicular emission

2/2

6. Estimation of vehicular emission load in terms of four major pollutants, viz. PM, CO, HC and NOx, in each of the 2 km x 2 km study zones using the traffic count data on each category of road and applicable emission factors (developed by ARAI).
7. Estimation of percent emission contribution (in terms of PM, CO, HC and NOx) for each category of road and also for different categories of vehicles in each of the study zones.
8. Estimation of SO₂ emission load based on diesel consumption (Sulfur in Diesel - 350 ppm).
9. Estimation of re-suspended dust load (in terms of PM₁₀ and PM_{2.5}) due to traffic movement on paved roads for each study zone.
10. Preparation of overall average traffic emission scenario based on the data collected for the ten 2 km x 2 km study zones.



Source: NEERI, 2010

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Then estimation of these pollutants like particulate matters CO, HC, SO₂, NO_x have been there in that area. So, how many vehicles are there it is easy to take those data from this RTO office and then calculate the emissions with the help of emission factors and the total like vehicle this how many kilometres one vehicle travel so, that average value can be taken and multiplication can be done very easily.

(Refer Slide Time: 17:45)

Line Source

Traffic survey for Vehicle Count

- In order to prepare **emission inventory** of vehicular (line) sources, **primary data on traffic count** were collected in the identified study zone.
- All types of vehicles moving on the arterial/ring roads, which are the main carriers of traffic in Delhi, were **counted manually round the clock from 8 am to 8 am** of the next day.
- Traffic was also counted on the road **nearest to the AQM (Air Quality Monitoring) site** (kerbside locations) for **12 hours duration**, between 8 am & 8 pm on non-working day (Sunday).

Source: NEERI, 2010





Image showing Traffic Count in Delhi



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So, the survey was conducted to have the primary data on different locations. So, that way some people, those who can do a good survey were hired and they counted vehicles at particular locations of different categories of the vehicles.

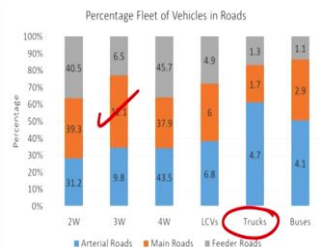
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Line Source

Road Category-wise Traffic Count

- The **traffic count data** has been analyzed for **three types of road categories**, viz. **arterial/ring roads, main roads and feeder roads** in each study zone.
- Based on the primary data collected in the study zones, composition of traffic has been calculated under **six broad categories of the vehicles**, namely; **2W, 3W, 4W, LCVs, trucks and buses**.

Source: NEERI, 2010

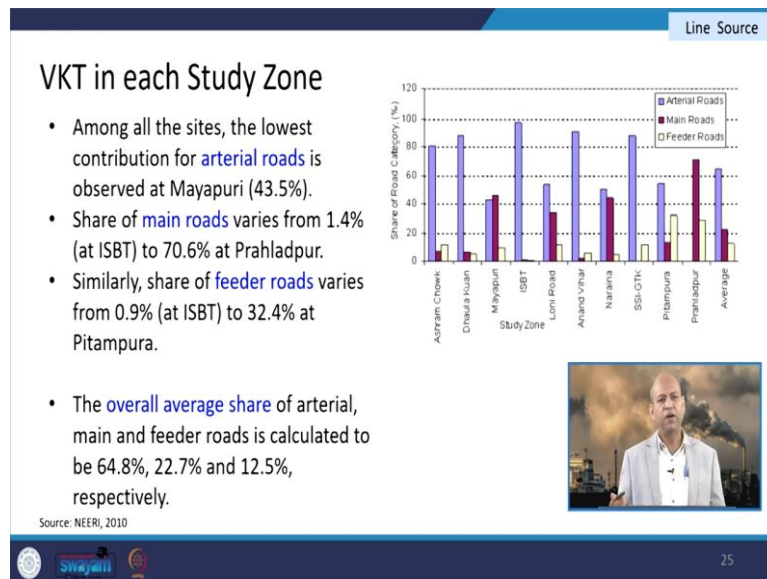


Vehicle Category	Arterial Roads (%)	Main Roads (%)	Feeder Roads (%)
2W	33.2	39.3	40.5
3W	9.8	14.4	6.5
4W	43.5	37.5	45.7
LCV	6.8	6	4.9
Trucks	4.7	1.7	1.3
Buses	4.1	2.9	3.1

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Then the road category wise do traffic count you can see here like the at the arterial roads, you can see most of the trucks are, plying on the arterial or the roads and the main roads are responsible for like 4 wheelers and these light commercial vehicles also in large number and 3 wheelers basically go on the main roads mainly. Than feeder roads are there. So, they are having like 45.7 percent if we count these, 4 wheelers, then they are mostly on these feeder roads are applying. So, those kinds of categorization have been done.

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Now, if you see this Vehicle Kilometre Travelled VKT needs steady zone. So, for each category of vehicle this VKT, it has been taken into account from different reports and those counting of vehicles plus, these VKT's and then emission factors have been used for emission estimations.


(Refer Slide Time: 19:05)

Line Source

Emission from Vehicular Sources

Assumptions

- **Fleet age composition** - In general, 85-95% of the vehicles are estimated to be about 10 years. All the autos are considered to be of CNG.
- **2S and 4S Two Wheeler** - ratio of 72:28 has been considered for 4 Stroke and 2 Stroke 2 Wheelers based on observed data.
- **4 Wheelers** – 92 % petrol, 5 % diesels and 3 % CNG
- **Buses** – 23 % Diesel, 77 % CNG
- **Emissions factors** developed by **ARAI** was used to estimate vehicular emissions.
- **SO₂ emission** is estimated based on fuel consumption.



Source: NEERI, 2010

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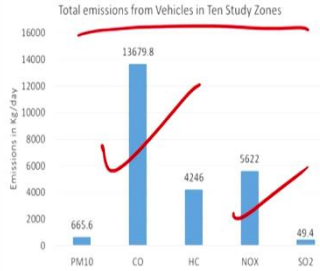
So, you can see the fleet age composition have been considered 2 stroke, 4 stroke, 2 wheeler ratio have been considered, then emission factors from ARAI has been used and the emissions have been estimated.

(Refer Slide Time: 19:18)


Line Source

Emission from Vehicular Sources

- The **total emissions** from the vehicular sources within the ten study zone were estimated.
- **CO** emissions was found to be the **highest** (13679.8 Kg/day) followed by **NO_x** emissions (5622 kg/day).
- **Lowest** emissions was observed for **SO₂** (49.4 kg/day)
- The **overall average** vehicular emission load in terms of PM, CO, HC, NO_x and SO₂ is estimated to be 65.8, 1355.9, 421.5, 557.4 and 4.9 kg/d respectively.



Pollutant	Emissions (kg/day)
PM10	665.6
CO	13679.8
HC	4246
NO _x	5622
SO ₂	49.4



Source: NEERI, 2010

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So, you can see the how many how many categories are there of the vehicles plus which pollutants like PM₁₀, CO, hydrocarbon, NO_x. So, total emissions of the vehicles in 10 is study zones if you see the maximum emissions are of the carbon monoxide (CO) and then second is the NO_x and then hydrocarbons, naturally from vehicular categories, these kinds of emissions are more basically.

(Refer Slide Time: 19:43)

Line Source

Vehicle Category-wise emissions

- PM emissions are mainly emitted by Trucks and LCVs,
- CO emissions are mainly contributed by 4-Wheelers (Petrol) and 2 & 4 Stroke 2-Wheelers.
- HC emissions are emitted by 2 Stroke 2-Wheelers and 2W-4 stroke, 3W-CNG as also 4W-Petrol.
- NOx emissions are mostly contributed by heavy duty vehicles (trucks and buses-CNG). LCVs along with 4W-P also contribute significantly.

Source: NEERI, 2010

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When we see vehicular category wise emissions, then like particulate matters are mainly emitted from the trucks as you can see around 48 percent. 38 percent or so the CO emissions are coming basically from 4 wheelers. So, if we want to, curb or we want to reduce the emissions of CO then we need to focus on 4 wheelers first if we talk about hydrocarbons, then they are mostly from 2 wheelers.

So, if you want to control hydrocarbons then better to control the 2 wheeler related technology, and NOx emissions are basically coming from like heavy duty vehicles, trucks etc. So, those are the major sources of different kinds of pollutants.

(Refer Slide Time: 20:25)

Line Source

Emission of re-suspended dust from vehicles

- Re-suspended dust in terms of PM₁₀ and PM_{2.5} from paved roads has been estimated based on the USEPA methodology, which involves estimation of silt loading (in g/m²), average weight of vehicles (tons/day), road length, rainfall days etc.
- ISBT and SSI-GTK dominates the road dust emissions among all the study zones due to high traffic.

Source: NEERI, 2010

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Well, then when we talk about, this re-suspended dust so, it has been estimated that near ISBT because a lot of vehicles are there on there, this bus depot, main bus depot is there and then, bus terminal and then this is small scale industry this Grand Trunk Road also has a lot of contribution of the road dust because of resuspension. So, these are basically two locations where a lot of dust suspension has been there.

(Refer Slide Time: 20:55)


Line Source

Pollutant-wise Identified Highest and Lowest Polluting Zones

Pollutant Emissions	Study Zone with Emission Load			
	Highest	High	Low	Lowest
Vehicular				
PM	ISBT	SSI-GTK	Anand Vihar	Prahladpur
CO	Ashram Chowk	ISBT & Dhaura Kuan	Loni Road	Prahladpur
HC	Ashram Chowk	ISBT	Pitampura	Prahladpur
NOx	ISBT	Ashram Chowki	Pitampura & Loni Road	Prahladpur
SO ₂	ISBT	SSI-GTK	Mayapuri	Prahladpur
Road Dust				
PM ₁₀	ISBT	SSI-GTK	Pitampura	Prahladpur
PM _{2.5}	SSI-GTK	ISBT	Prahladpur	Pitampura

- Based on the vehicular emissions, most polluted zones was ISBT, Ashram Chowk and SSI-GTK.
- Least polluted zone were Pitampura and Prahladpur.

Source: NEERI, 2010

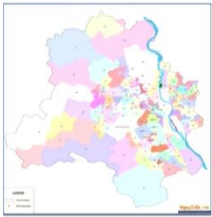


Well, the pollutant wise identified highest and lowest polluting zones if we want to consider. So, the particulate matter highest is from ISBT area. And this then high is from the small scale industry, Grand Trunk Karnal Road and lowest is in Prahladpur. Similarly, for different, like hydrocarbon, this highest in Ashram Chowk lowest in Prahladpur. So, Prahladpur you can see mostly that is the lowest emitting sector or location or the zone for different kinds of pollutants.


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City level Emission Inventory

- The emission inventory of the ten study zones has been used to estimate through extrapolation method for total emissions for the whole of the Delhi.
- The main purpose of 2 km x 2 km study zones is to accurately identify and quantify emissions from different sources to be used to predict air quality in the study zones and compare the predicted air quality levels with the measured air quality levels.
- Emission inventory has been prepared in terms of five major pollutants, viz. PM₁₀, SO₂, NO_x, CO and HC.



Delhi city



Source: NEERI, 2010

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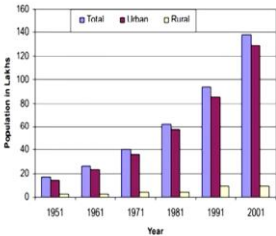
Well, when we talk about city level, because these were the zone whatever 10 zones were selected by these, researchers, those were the emission inventory developed. So, city level emission inventory was developed based on those emission inventories of 10 zones basically, so extrapolation or projection you can say have been done based on the emission estimations which have been done in those particular zones.

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Data collection at City Level

Population data


- Census data such as number and locations of wards/sectors ward wise map and ward-wise population etc. was collected.
- As per census 2001, slum population in urban areas of Delhi is of about 26.6 lakhs.



Year	Total	Urban	Rural
1951	15	10	5
1961	25	18	7
1971	40	28	12
1981	60	45	15
1991	95	75	20
2001	140	110	30

Fuel consumption

- Annual fuel supply with respect to various fuels obtained from Petroleum Planning and Analysis Cell (PPAC) for the period 2001-02 to 2006-07.
- Data on total Kerosene supply in Delhi was collected from Food Supplies and Consumers Affairs Department.



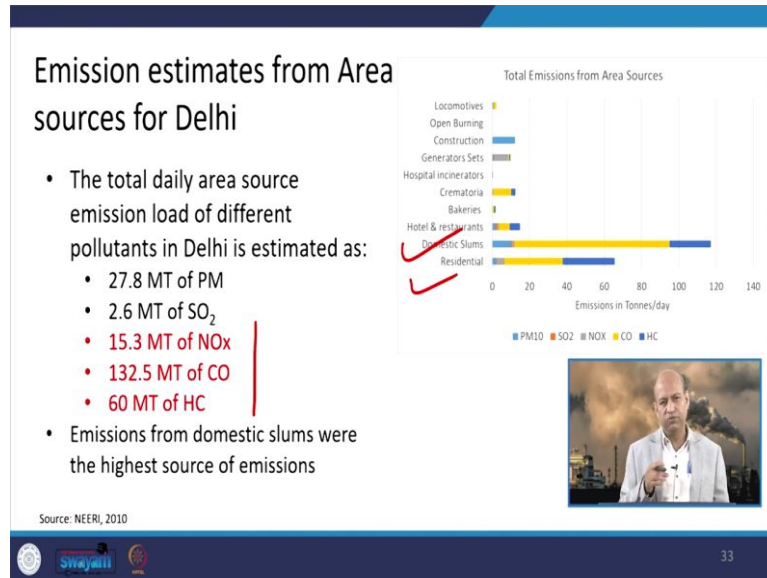
Source: NEERI, 2010

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So, there have been, estimations or projections based on certain things like population data, how much fuel consumption is there. So, census data has been taken and then fuel consumption has been taken from different reports, you can see this population in lakhs and the slum

population as well as urban population ruler population, those kinds of population data have been taken.

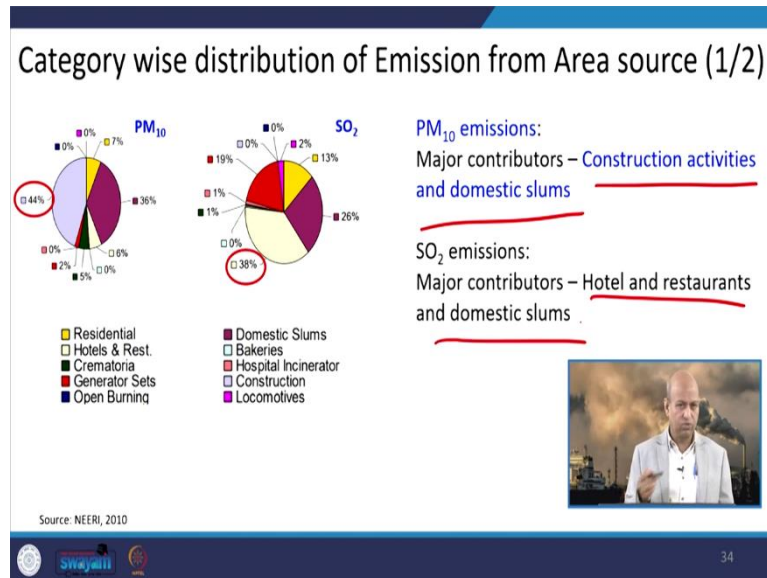
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So, the emission estimates from area sources were taken from projections of those estimated values. So, it was seen that domestic slumps were responsible for the maximum emissions of carbon monoxide and hydrocarbons and residential area was also the responsible. So, these two major areas where they are for emissions, large amount of emissions, and basically if you see these NO_x emissions and CO emissions and the hydrocarbon emissions, they are the dominating ones even in area sources.

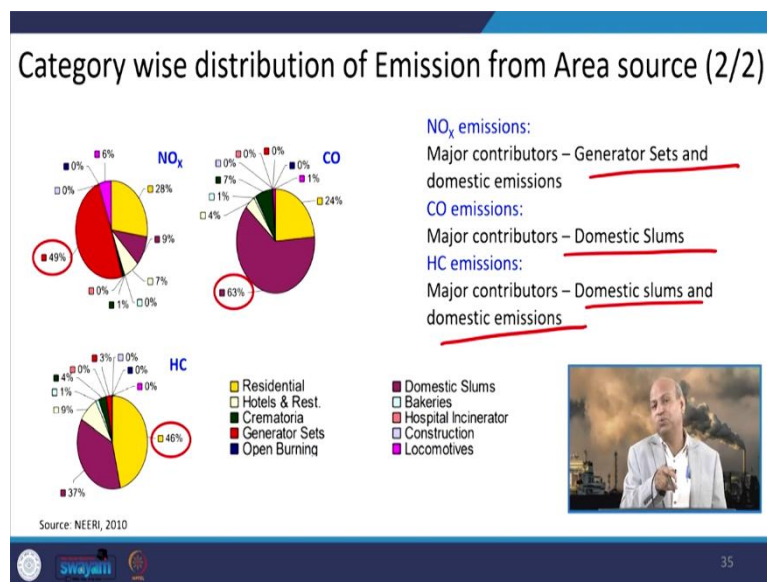
So, that is the situation to worry some because, these are the precursors of ozone. So, in case, ozone production starts to take place in summer or wherever solar insolation is good, then this is another big problem which, we can foresee and we have to think seriously about reducing these emissions.

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Well, when we talk about category wise distribution of emissions from area sources, so you can see like 44 percent is coming, this PM₁₀. So, Major 44 percent is coming from these construction activities and domestic slumps. SO₂ emissions in large quantities coming from hotels restaurants, because they use those kinds of fuels, coals etc. So, again, domestic slumps are also there in this particular contribution for SO₂.

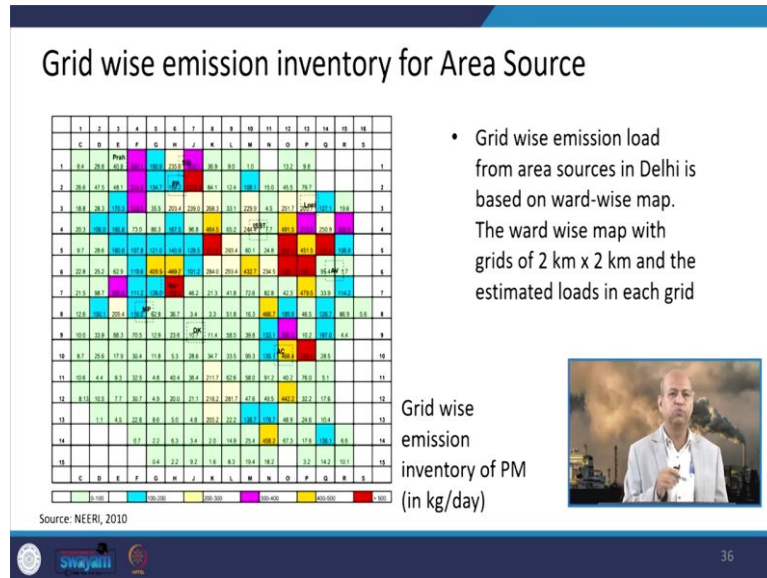
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So, we hope to see, pollutant wise like NO_x emissions, mostly coming from generator sets or domestic emissions CO emissions from domestic slumps, hydrocarbons, again from domestic slumps and domestic emissions. So, you can see, these areas sources are also respond because we have seen that these CO hydrocarbon etc knocks they come large in quantity in from vehicle

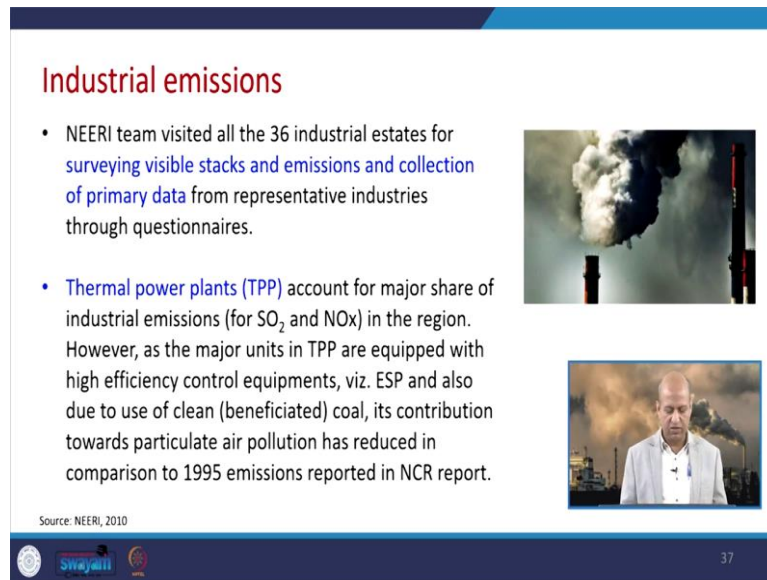
category which we will see again. But area sources are also giving this large quantity and that is the worrisome issue.

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Then this grid wise emission inventory has been developed, so that we can know which particular areas are there where lot of emissions are coming from. So, you can see this red colour area, they are the most responsible for a large amount of the emission.

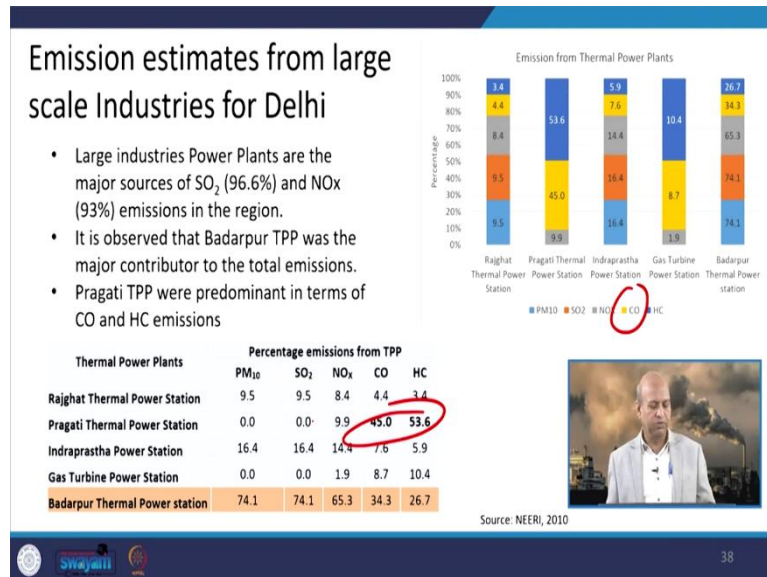
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So, that we can first go and see how, what we can do to reduce in particular those kinds of hotspots, where lot of emissions are coming from. When we talk about like this industrial emission. So, as I said earlier that these NEERI team visited all, industrial areas and counted how many stacks are there for different kinds of emissions. So, they have taken also into

account like what kind of technologies they are using, like if ESPs are being used then particulate matter emissions are very low because that is effective for reducing the emissions, but then the SO₂, NO_x emissions are also coming.

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So, you can see emissions from thermal power plants and lot of emissions are there off again CO and then like from Pragati thermal, the CO emission and this hydrocarbon emissions are quite high, well when we talk about again this gas turbine power station, so same story is there, but, if you talk about NO_x emissions, then this Indraprastha and Rajghat and Badarpur they are quite significant amount of NO_x emissions are also there.

So, we can see percentage emissions from these thermal power plants and Badarpur thermal power plant is responsible for quite high amount of PM₁₀ and SO₂ but this Pragati thermal is responsible for highest amount of CO and hydrocarbon. So, that way we can see which power plant is emitting which kind of pollutant in a large quantity.

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Emission estimates from medium scale industries

- The emissions estimated for 2252 SSI units located in 36 industrial estates is shown in figure.
- NO_x emissions (24877 kg/day) was the maximum from small scale industries, whereas CO (1841 kg/day) was minimum.

Source: NEERI, 2010

Well, when we see these emission estimates from small scale and medium scale industries, so, basically when we talk about medium scale industries, again the dominating emissions are of NO_x emissions. So, as I said that, this in Delhi basically these NO_x , CO hydrocarbons etc, they are the things to be concentrated upon based upon this particular study. It is all the study and maybe appropriate policy measures were implemented based on this particular study.

(Refer Slide Time: 26:18)

Emission estimates from all industries

- The emissions from all the scales of industries (small, medium, large) is presented in the figure.
- The percentage contribution indicates that the large scale industries are the major sources of emissions, especially, for PM_{10} and NO_x .

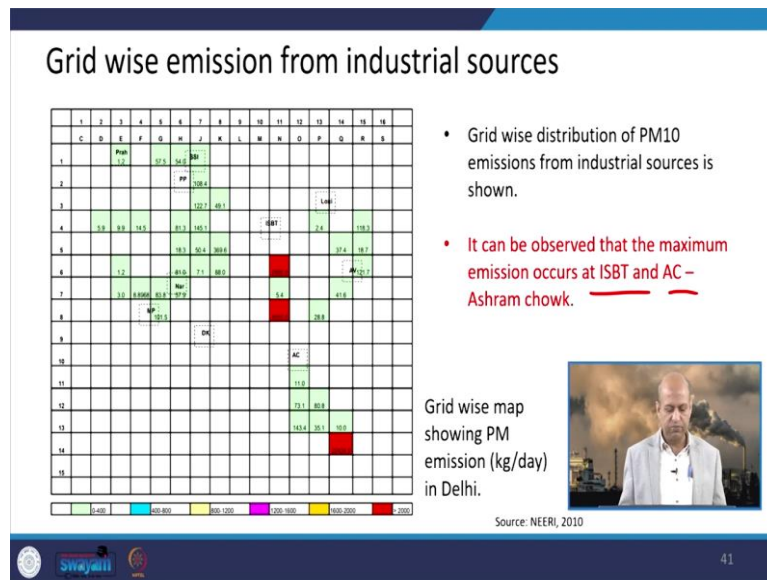
Industries	Percentage contribution to emissions				
	PM_{10}	SO_2	NO_x	CO	HC
Small Scale Industries	6.4	1.7	6.9	38.6	21.2
Medium Scale Industries	0.4	1.7	0.1	0.4	0.4
Large Scale Industries	93.1	96.7	93.0	61.0	78.5

Source: NEERI, 2010

Here also, like large scale industries are responsible for like PM_{10} , NO_x etc, and CO are from small industry, a small scale industries. So, a small scale industries are responsible for CO as well as, largest scale industry. So, fear share is there you can say, otherwise for PM_{10} , SO_2 and NO_x dominating source are the large-scale industries.

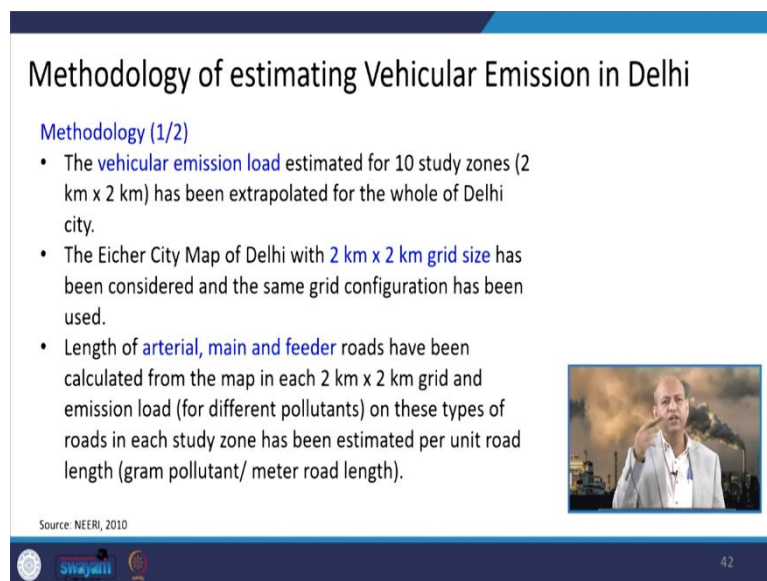
So, again, you can see what is the contribution or percentage contribution of different industries for different pollutants. So, large scale industries are responsible for, very high amount of all kinds of emissions of course, but like if you talk about CO, then small scale industries are also very much responsible.

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Well again, so grid wise admission inventory was development distribution of these emissions were grid wise so that we can know the hotspots. So, you can see here, this is ISBT and this Ashram Chowk have been identified as a large amount of these emissions.

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Well, so methodology for estimating vehicular emissions. Now, we come to so methodology as I said, this is based on VKT Vehicle Kilometre Travelled and the emission factors. So, in


those 2 kilometre x 2 kilometre, they were estimated and those were projected for Delhi basically.

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Methodology of estimating Vehicular Emission in Delhi

Methodology (2/2)

- As per the map, the total length of arterial/ring roads/NHs is found to be 472 km, main roads (next category roads to arterial roads) 355 km and main feeder roads – 2002 km. Traffic on minor roads/street roads is considered to travel a distance of 100-200 m and it joins any other category of road, hence these types of roads are not considered in the emission load calculations



Source: NEERI, 2010


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So, the total length of roads have been identified for different kinds of roads like ring roads, and then, feeder roads or those kinds of these arterial roads, all these kinds of roads. So, how many vehicles are plying on those particular roads. So, those data have been used for extrapolation of those estimations which were taken from the specific zones.

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Emissions estimates from Vehicular emissions

- Total daily vehicular emission load (in Metric tonnes) in Delhi for sources different pollutants is estimated as:
 - 9.75 MT of PM
 - 217.8 MT of CO
 - 66.7 MT of HC
 - 84.2 MT of NO_x
 - 0.72 MT of SO₂
- Daily re-suspended road dust emissions in terms of PM₁₀ and PM_{2.5} is estimated to be 77.3 MT and 5.7 MT

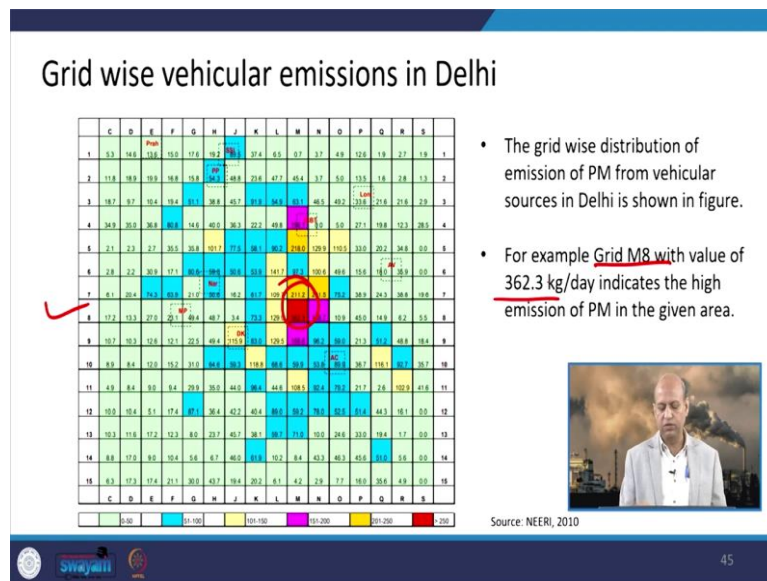


Source: NEERI, 2010

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And we can see like a lot of emissions again of this NO_x emission and the hydrocarbons and CO. So, they are also it is very intuitive that vehicular emissions mostly emit those kind of emission, NO_x emissions and CO emissions.

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- The grid wise distribution of emission of PM from vehicular sources in Delhi is shown in figure.
- For example Grid M8 with value of 362.3 kg/day indicates the high emission of PM in the given area.



And you can see again distribution. So, to identify the hotspots, you can see like these kind of grids are there, which are responsible for like grid M8, this 8 and this M so, this M8 grid is very much responsible for high value of particulate matter, if you see around 362 kg per day.

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Identified Hotspots in Delhi based on emission inventory (1/2)

<p>Grid Grid Affected Prominent Areas/Locality</p> <p>M8 India Gate, Rajpath, Vigyan Bhawan, Udyog Bhawan</p> <p>M5 ISBT, Kashmere Gate, Tis Hazari Court, Stephens Hospital</p> <p>M9 Lodi Garden, Lodi Estate, UNO, India Habitat Centre</p> <p>M7 Connaught Place, Jantar Mantar, Mandi House Chowk</p> <p>L9 Race Course, Hotel Ashok, Hotel Samrat, Delhi Gymkhana Club</p> <p>L8 Central Secretariat, Sansad Bhawan, Rashtrapati Bhawan</p> <p>N7 Firoz Shah Kotla, ITO, Mandi House, Maulana Azad Medical College, GB Pant Hospital, LNJP Hospital</p> <p>M4 Delhi University, Timarpur Chowk, Vidhan Sabha</p> <p>N8 Supreme Court, Pragati Maidan, WHO, Indraprasth, Delhi High Court</p> <p>K10 Moti Bagh, Netaji Nagar, R.K. Puram</p> <p>L6 Karol Bagh, Sadar Bazar, Motia Khan, Jhandewalan</p> <p>J9 Dhaura Kuan Area</p> <p>Q10 Toll Plaza, Chilla, Alka Cinema</p> <p>N5 GPO, Indraprasth University, Nigambodh Ghat</p> <p>P4 Loni Golchakkar, Durgapuri Chowk, Balbir Nagar, Babarpur</p> <p>J1 Makraba Chowk (SSI-GTK area), Jahangirpuri, Rajiv Nagar</p>	<p>Based on the emission inventory, the most affected grids with prominent areas and localities are identified, which can be termed as hotspots.</p>
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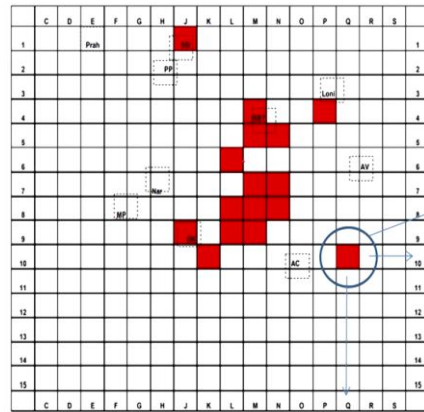
Source: NEERI, 2010



So, that particular methodology was used for identification of hotspots and those hotspots are like M8, M5, so, these are the names of the grids and these grids include those particular prominent areas like M8 India Gate, Rajpath, Vigyan Bhawan, Udyog Bhawan. So, lot of emissions from vehicle categories, maybe there. Then is ISBT, Kashmere gate and you can see all these kind of names, which are in particular grids are there.

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Identified Hotspots in Delhi based on emission inventory (2/2)



The red grid indicates the identified hotspots in Delhi.

For example:

Grid No. Q10:
Toll Plaza, Chilla, Alka Cinema



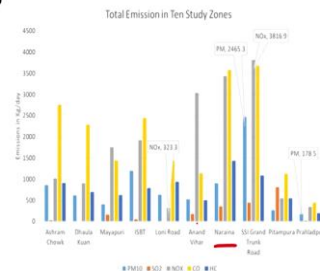
Source: NEERI, 2010

Well, so to identify the hotspots then grid number 10, Toll Plaza, Chilla these Alka Cinema, they have been identify. So, you can see the grid and you can see which places are there which need to take the attention of the policymakers.

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Total emission in ten study zones

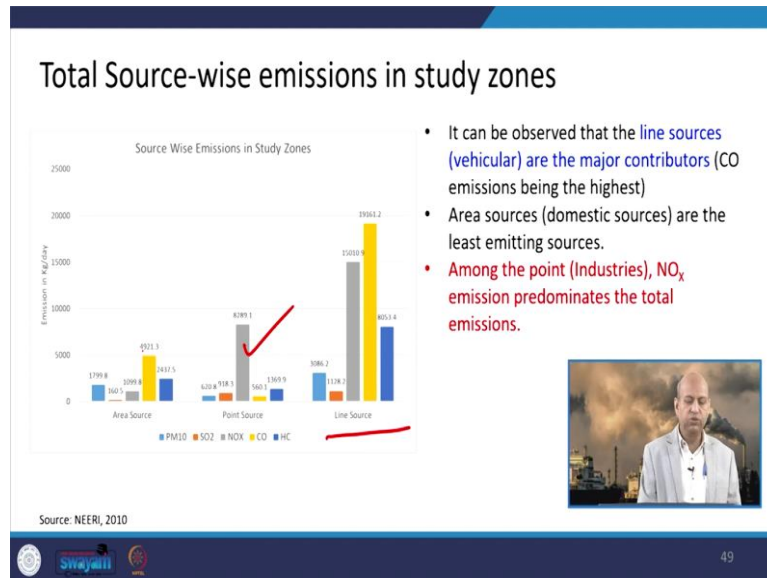
- Among the ten study zones, estimated emission load for
 - PM ranges between 178.5 kg/d (at Prahladpur) and 2465.3 kg/d (at SSI-GTK),
 - SO₂ ranges between 8.3 kg/d (at Loni Road) and 814.1 kg/d (at Pitampura),
 - NO_x ranges between 323.3 kg/d (at Loni Road) and 3816.9 kg/d (at SSI-GTK),
 - CO ranges between 442.8 kg/d (at Prahladpur) and 3681.8 kg/d (at SSI-GTK),
 - HC ranges between 195.1 kg/d (at Prahladpur) and 1432.0 kg/d (at Naraina).



Source: NEERI, 2010

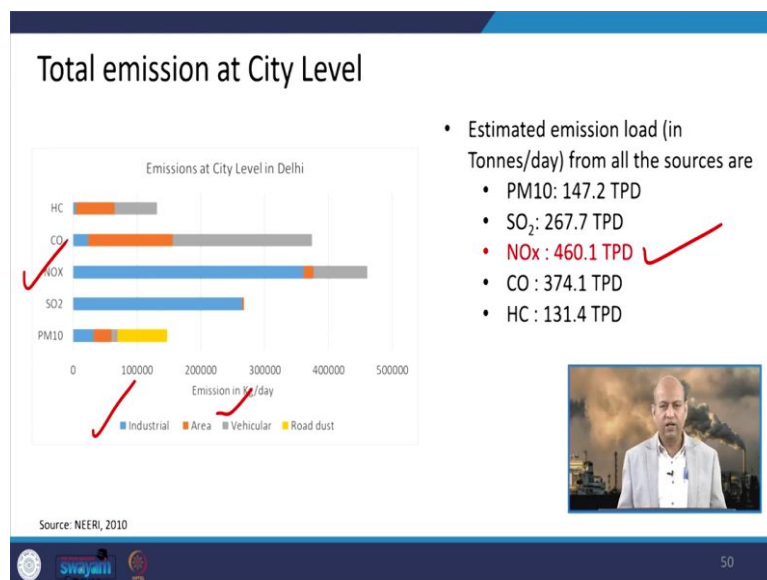
Well, when we talk about the total emissions in 10 study zones, so there are, variations are there like you can see these as I said a small scale industrial Grand Trunk Road and the Naraina and they are dominating for particulate matter and NO_x emissions you can say. So, that we different kind of zones have different kinds of information.

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But when we talk about total source emissions, these study zones then line source emissions are dominating basically for these NO_x as well as carbon monoxide that is a vehicular category basically, point source is dominating NO_x for NO_x in point source. And in area source, CO is more so, that way you can see which pollutant is coming more from which particular source category.

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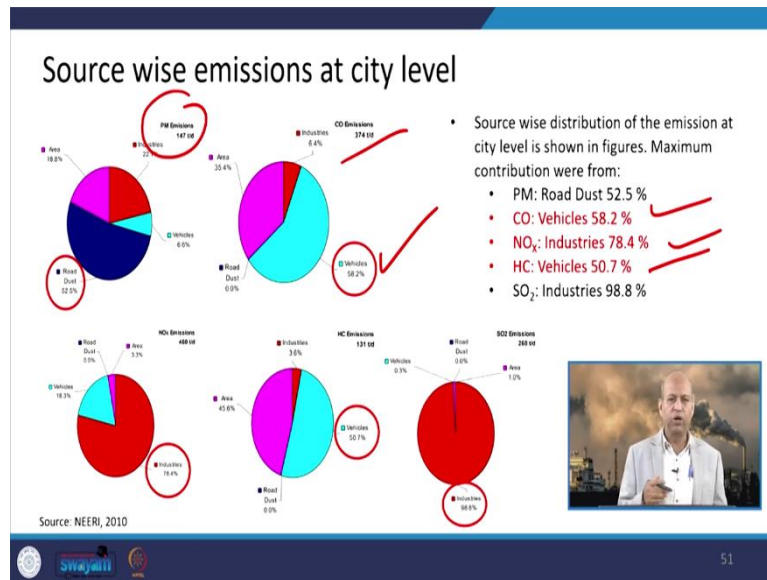


Well, when we talk about at the city level, so the NO_x emissions are the highest basically and they are coming from industrial as well as vehicular emissions, this NO_x. Second is CO which is coming, majorly from vehicular and then the second is from area sources. So, and SO₂ is

basically coming from industrial sources. So, these kind of information is there and as you can see this a lot of emissions of NO_x is there.

And I always, repeated that, because of NO_x and CO hydrocarbons etc peak occurs of ozone. So, we should be quite sensitive or sensitive about these kinds of pollutants, how to reduce them because they may create another problem in future if we do not give you attention.

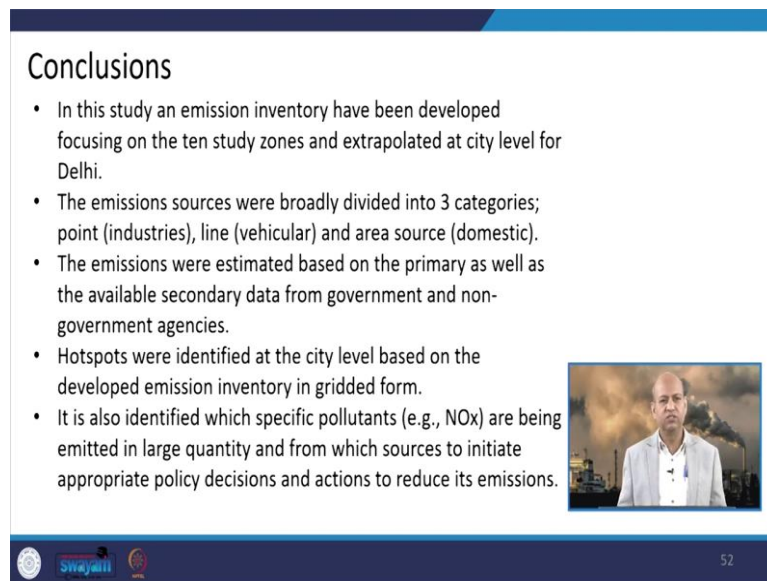
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Well, source why emissions at the city level also you can see like these CO emissions NO_x emissions, hydrocarbon emissions, they are dominating PM emissions like 52.5 from the road dust basically. So, that is the major source, but for CO emission the vehicle categories are the most, second is area source for these hydrocarbons again vehicle and area source are responsible and for NO_x emissions again industries and vehicle categories industries are more responsible.

So, that way you can see like, SO₂ only industries are there to control. So, according to their amount we can look into that which kind of shows we need to first focus upon to apply certain policy interventions or technological intervention, so, that those emissions can be reduced and air quality can be improved.

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Conclusions

- In this study an emission inventory have been developed focusing on the ten study zones and extrapolated at city level for Delhi.
- The emissions sources were broadly divided into 3 categories; point (industries), line (vehicular) and area source (domestic).
- The emissions were estimated based on the primary as well as the available secondary data from government and non-government agencies.
- Hotspots were identified at the city level based on the developed emission inventory in gridded form.
- It is also identified which specific pollutants (e.g., NO_x) are being emitted in large quantity and from which sources to initiate appropriate policy decisions and actions to reduce its emissions.

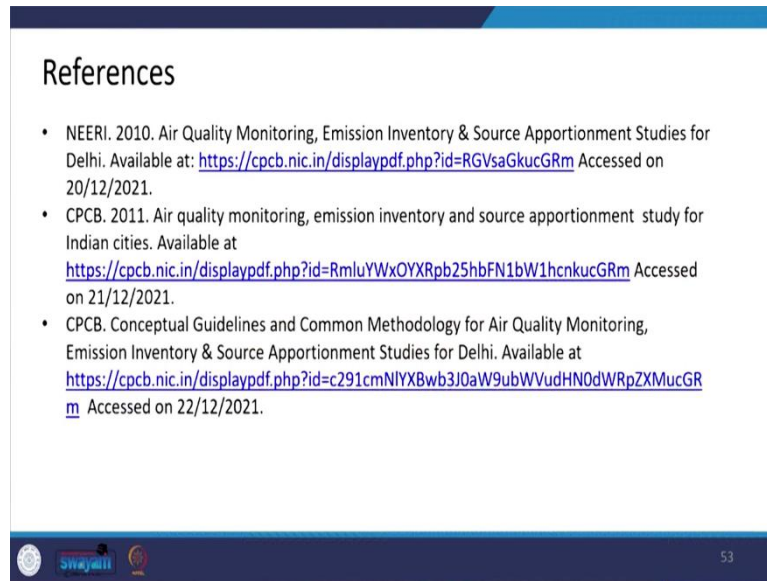
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So, this is basically, case study how these emission inventories are developed and how they are, used for inferring information or insights, as we have seen which kind of pollutants are more and how to focus upon some policy decisions or technological interventions specifically for those pollutants, otherwise, they will create some other problems, whether health related or ecological related.

So, we can say that in this study, we have seen the emission inventory, which was developed focused on certain zones and then extrapolation has been done for city level and then hotspots were also identified. And it is also identified that specific pollutants like NO_x are being emitted in large quantity from different sources and we can categorise or target those sources to reduce the emissions of NO_x or CO and hydrocarbons.

So, that we do not fall into that kind of problem of for ozone products and because ozone is a very hazardous, pollutant in the troposphere, although it is good in the stratosphere as you know. So, those kinds of inferences or insights can be developed by these kinds of inventories. So, I hope you like this particular case study.

(Refer Slide Time: 33:24)



References

- NEERI. 2010. Air Quality Monitoring, Emission Inventory & Source Apportionment Studies for Delhi. Available at: <https://cpcb.nic.in/displaypdf.php?id=RGVsaGkucGRm> Accessed on 20/12/2021.
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And these are the references where we have taken information for this particular case study, and you can go through this information in your free time. So, this is all for today. Thank you very much for your kind attention. See you in the next lecture. Thanks again.