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MODELLING PLUME RISE FROM AN INDUSTRY BY USING AERMOD: AN AIR QUALITY DISPERSION MODEL

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Abstract: The present study is proposed to determine the possibility of using AERMOD atmospheric dispersion modelling system to estimate the air pollutant levels of plywood factory located at Lakshmi Doors, Semra, Chinhat, Lucknow 226028. Four main pollutants PM_{10}, $PM_{2.5}$, CO, and NO_x are considered in this study. The metrological data are to be obtained from CPCB for comparison with the model's output. The primary pollution sources used in this study is an output draught. Emission characteristics are to be taken as source input to estimate the pollutant concentration from the study area based on the Top-Down Approach method (TDA).

***IndexTerms* – AERMOD, PM_{10}, $PM_{2.5}$, CO, NO_X, CPCB, TDA**

INTRODUCTION

Air pollution is defined as the presence of toxic chemical and compounds in the atmosphere which is harmful for human health and environment which may come from human activities and natural sources.

Air pollution is a major global environmental problem that poses risks to both human health and ecosystems. These contaminants can take many forms, including gases, particulates, volatile organic compounds (VOCs), and toxic chemicals.

The sources of air pollution are diverse and include vehicle exhaust, industrial exhaust, agricultural activities, power generation, and domestic activities such as cooking and heating. Natural phenomena such as volcanic eruptions, wildfires, and dust storms can also cause air pollution. When pollutants are released into the atmosphere, they degrade air quality and can have serious consequences.

Air pollution is a familiar environmental health hazard. The main cause of air pollution is the presence of foreign pollutants in air. Air pollution is the presence of one or more pollutants such as dust, fumes, odour, smoke, mist, etc. Air pollution is mainly caused by rapid industrialization.

Air pollution through stack

In present day, large number of industries is established in India. Rising plume in many industries will affect our environment. Air pollution from chimney exhaust is a major contributor to overall air pollution, especially in the industrial and commercial sectors. Stack emissions are the release of pollutants into the atmosphere through stacks and chimneys from various industrial processes, power plants, and other sources of combustion. These emissions can adversely affect local and regional air quality.

Industrial activities often release various pollutants into the atmosphere, such as particulate matter, gases, and volatile organic compounds (VOCs). These emissions can adversely affect local air quality and lead to increased pollutant concentrations near sources. The term "plume rise" refers to the vertical movement of the pollutant plume as it emerges from the chimney.

Stack emissions include particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), Volatile Organic Compounds (VOCs), and Hazardous Air Pollutants (HAPs). , which often contain various contaminants. These pollutants can adversely affect human health, ecosystems and the environment.

Fig.1: Air Pollution from stack

Meteorological Factors Influencing Air Pollution

The amount of air pollutants that are released from different sources concentrated in a particular area depends largely on meteorological conditions.

The important meteorological parameters that influence the air pollution can be classified into Primary and Secondary Parameters.

Primary Parameters are:

i. Wind direction and speed
ii. Temperature
iii. Atmospheric stability
iv. Mixing height

Secondary Parameters are:

i. Precipitation
ii. Humidity
iii. Solar Radiation
iv. Visibility

Temperature Inversion

Under normal conditions, temperature decreases with increase in elevation. At times, the situations get reversed and temperature starts increasing with height rather than decreasing. This is called ***Temperature Inversion.***

Fig.2: Temperature Inversion

Types of Temperature Inversion

1. Non- Advectional (Static) Temperature Inversion

A. Ground/Surface/Radiation Inversion:

- It occurs near the earth surface due to radiation mechanism.
- It develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere. This occurs most often on clear nights, when the ground cools off rapidly by radiation.

2. Upper Air Inversion

A. Subsidence Inversion:

- In this, the descending layer is compressed and adiabatically heated by the increase in atmosphere pressure (dry adiabatic rate of 9.8°C/km). Thus causing lying of warm air above cold air, producing a temperature inversion.

B. Turbulence & Convective Inversion:

- Sometimes due to eddies (whirls of winds) formed by frictional forces, warm air is suddenly transported upwards to the zone of cold air. Warm air being less dense, settle over cold air, causing inversion.

3. Advectional (dynamic) Temperature Inversion

A. Frontal or Cyclone Inversion:

- In this type of inversion there is a convergence of warm and cold air mass.
- The warm air being lighter goes upward and the cold air being heavier skin down.
- This kind of inversion has a considerable slope, whereas other inversion are nearly horizontal.

B. Valley inversion:

- It generally occurs in mountainous valleys due to radiation.
- During winter nights, the upper surface radiates heat and get cooled. The air becomes denser and descends downhill into the valley under the influence of gravity to pile up in pockets and valley bottoms with warm air above. This is also called ***air drainage***.

Plume Behaviour

The diffusion of pollutants in the atmosphere is known as plume behaviour. It is controlled by environmental lapse rate and adiabatic lapse rate.

The plume behaviour emitted from any stack depends upon localized air stability. Factors influencing plume behaviour are the diurnal variations in the atmosphere stability and the long term variations which occurs with changing season. The speed of plume behaviour is directly related to the vertical temperature gradient.

There are seven types of plume behaviour:

1. **Looping:** This type of plume behaviour which has a wave like character and occurs in a highly unstable atmosphere because of rapid mixing.
2. **Coning:** This type of plume behaviour which have a cone like shape. It occurs near neutral atmosphere when wind velocity is greater than 32km/hr.
3. **Fanning:** This type of plume emitted under extreme inversion condition. In this, the plume spread horizontally, but little, if at all vertically.
4. **Lofting:** It occurs when there is a strong lapse rate above a surface inversion. Under this condition the diffusion is rapid upward, but downward diffusion does penetrate into the inversion layer.
5. **Fumigation:** This is a phenomenon in which pollutants that are a loft in the air are bought rapidly to the ground level when the air destabilized.
6. **Trapping**: In this the plume is caught between the inversions and can diffuse within a limited height.
7. **Neutral:** This type of plume rise vertically in upward direction. It will continue to rise at a certain height where density and temperature of air are equal.

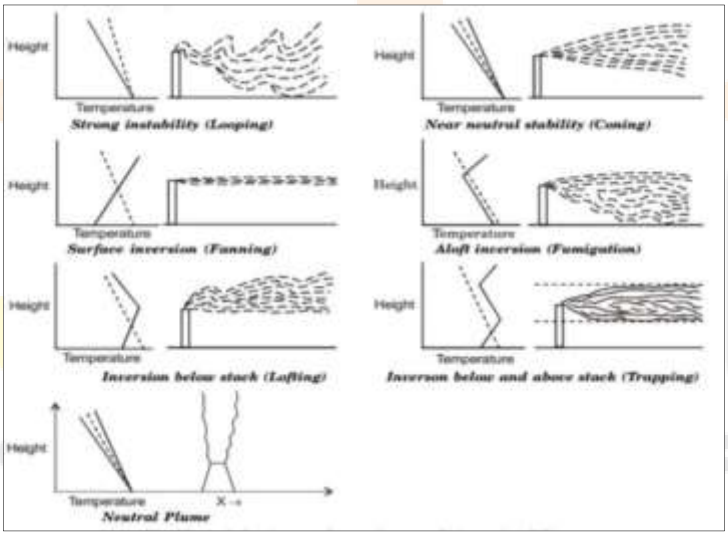


Fig.3: Types of Plume Behaviour

AERMOD

AERMOD was developed by the *American Meteorological Society* (AMS) and *EPA Regulatory Model Improvement Committee (AERMIC)* in early *1990*.

The AERMOD modelling consisting of mainly two components: (i) AERMOD Dispersion Model and (ii) AERMET Meteorological Preprocessor.

AERMET is responsible for preparing and processing the meteorological data, such as wind direction, wind speed, temperature, and stability class, which are crucial inputs for AERMOD. AERMET processes these meteorological data to generate the necessary input files required by AERMOD.

AERMOD determines the amount of pollutants present at receptor point downstream of the emission source. The receptor can be located at various distance and direction from the source representing the locations of interest where the air quality impact is assessed. To determine the dispersion of pollutants, the model accounts for the impacts of atmospheric turbulence, wind direction, speed, and temperature, as well as other site-specific parameters.

AERMOD is frequently employed for regulatory compliance tasks, such as obtaining permits and evaluating the environmental effect of potential industrial facilities or changes to existing ones. In order to assess the potential health hazards related to exposure to pollutants, it gives estimates of pollutant concentrations that may be compared to air quality requirements.

AERMOD is a steady state Gaussian plume dispersion model aimed at short range nearly 50 KM air pollution dispersion. It is used extensively to assess pollution concentration and deposition from a wide variety of sources in locations all over the world. The atmospheric dispersion models are often used to predict downwind concentrations of the emitted pollutants or to derive emission rates through AERMOD. Among various types of software for modelling Gaussian Modelling is widely used for describing dispersion of air emissions.

AERMOD (Atmospheric Dispersion Modeling System) is a widely used air dispersion model that predicts the transport and dispersion of air pollutants emitted from industrial sources. It is a regulatory model that aids in determining how air pollution affects ambient air quality, particularly in areas close to industrial facilities like factories, power plants, and chemical plants.

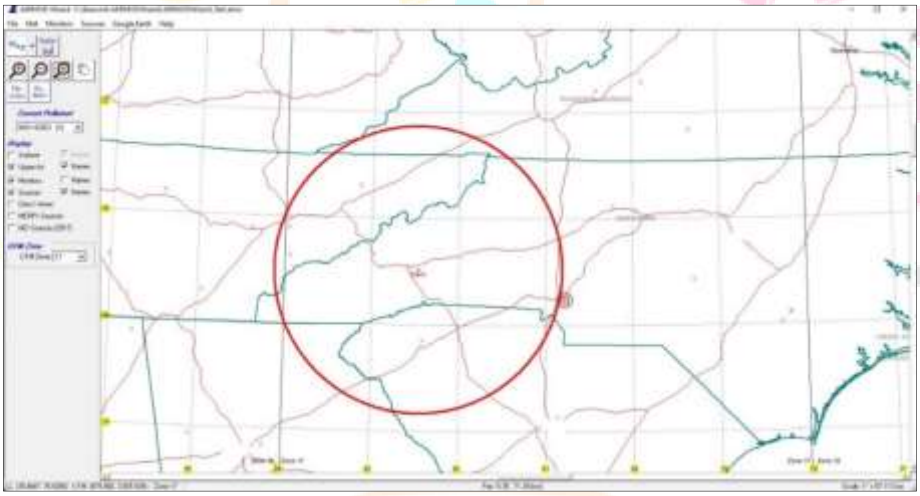


Fig.4: AERMOD User Interface

LITERATURE REVIEW

1. Model Description and validation studies

AERMOD and its underlying ideas have been thoroughly described in a number of studies. An overview of AERMOD's algorithms, input specifications, and output possibilities was provided by **Cimorelli et al. in (2005)**. They highlighted the model's advantages and disadvantages while discussing the model's capacity to forecast plume rise and contrasting its performance with that of other widely employed dispersion models.

Numerous validation experiments have been carried out to assess AERMOD's accuracy in modelling plume rise. **Briggs (1993)** found good agreement between AERMOD forecasts and observations made from large stacks, demonstrating the model's capacity to replicate plume ascent. Similar to this, **Venkatram and Wyngaard (2004)** evaluated the model using a variety of field data and showed that AERMOD achieved accurate plume rise forecasts under various atmospheric stability circumstances.

2. Meteorological input and atmospheric stability

Venkatram, A (1999) studies and examine the influence of stack parameters such as stack height, temperature, exit velocity and diameter on plume rise. It highlights the importance of stack characteristics for determining the behavior of plume and their subsequent dispersion patterns.

Using AERMOD, several research have examined how stack characteristics affect plume rise modelling. To evaluate the effect of stack height, diameter, and exit velocity on plume rise forecasts, **Liu et al. (2012)** performed a sensitivity study. They found that exit velocity had a relatively little impact, while stack height had the greatest impact.

The impact of several stacks and their arrangement on plume ascent has also been researched. **Castro et al. (2018)** examined the effects of staggered and inline stack arrangements and discovered that the arrangement affected the characteristics of the plume rise and the subsequent ground-level concentrations.

3. Influence of Stack Characteristics

The impact of stack characteristics on AERMOD-based plume rise modelling has been examined in a number of studies. A sensitivity analysis was carried out by **Liu et al. (2012)** to evaluate the effects of stack height, diameter, and exit velocity on plume increase forecasts. They found that exit velocity had a relatively little impact, but stack height had the biggest impact.

Lodhi et al. (2012) studied and examine the influence of stack height using AEMOD software. The relationship between stack height, plume rise, and the dispersion of pollutants is explored, highlighting the importance of stack characteristics in foretelling dispersion patterns.

Additionally, research has done on the impact of many stacks and how they are arranged on plume rise. **Castro et al. (2018)** studied the effects of staggered and inline stack arrangements and discovered that the arrangement affected the ground-level concentrations and the features of the plume rise.

MATERIALS

Pollutants release from plywood factory

The pollutants release from stack of a plywood factory are:

i. Formaldehyde
ii. $PM_{2.5}$
iii. PM_{10}
iv. Sulphur di-oxide (SO_2)
v. Nitrous Oxide (NO_X)
vi. Carbon Monoxide (CO)

Formaldehyde: Aldehyde systematic name methanal is a naturally occurring organic compound with the formula CH2O and structure H−CHO. The pure compound is a pungent, colourless gas that polymerizes spontaneously into paraformaldehyde), hence it is stored as an aqueous solution (formalin), which is also used to store animal specimens. It is the simplest of the aldehydes (R−CHO). The common name of this substance comes from its similarity and relation to formic acid.

$PM_{2.5}$: Particulate Matter refers to the complex mixture of solid, liquid and particles present in suspended air. These particles vary in size, composition, and origin, and they can have a big effect on the environment and on people's health.

Fine particles with a diameter of 2.5 micrometers or less are specifically referred to as $PM_{2.5}$.

PM2.5 are very small particles usually found in smoke. They have a diameter of 2.5 micro meters (0.0025 mm) or smaller. PM2.5 particles are a common air pollutant.

Common sources of $PM_{2.5}$ particles includes smoke from fires, smoke from wood heaters, smoke from wood heaters, car and truck exhausts, industry, etc.

Breathing in PM2.5 particles can affect your health. PM2.5 particles are small enough for you to breathe them deeply into your lungs. Sometimes particles can enter your bloodstream. People who are sensitive to air pollution might experience symptoms when $PM_{2.5}$ levels are high. This includes people with heart or lung conditions. Symptoms can include: wheezing, coughing, chest tightness, and difficulty in breathing.

PM_{10}: Particulate Matter refers to the complex mixture of solid, liquid and particles present in suspended air. These particles vary in size, composition, and origin, and they can have a big effect on the environment and on people's health.

Fine particles with a diameter of 10 micrometers or less are specifically referred to as PM_{10}. These particles are produced from a variety of sources, have a wide range of sizes, and a variety of compositions. PM_{10} particles are larger than $PM_{2.5}$ particles but still small enough to be inhalable.

PM_{10} can be released directly into the atmosphere by anthropogenic activities (industry, housing, agriculture, transportation) and natural sources (forest fires, volcanic eruptions, etc.). Particles can also be formed directly in the atmosphere by physio-chemical reactions between pollutants already present in the atmosphere.

Sulphur Dioxide (SO_2): Sulphur and oxygen combine to form the gaseous molecule known as sulphur dioxide (SO_2). It contributes significantly to the chemistry of the atmosphere and environmental contamination, and it is produced by both natural and artificial activities.

Volcanic eruptions, geothermal processes, and the oxidation of sulphur-containing materials are all examples of natural sources of SO_2. However, the main causes of the increased amounts of SO_2 in the atmosphere are anthropogenic sources, mainly the burning of fossil fuels. Anthropogenic SO_2 emissions are mostly produced by industrial processes like electricity generation, smelting operations, and fuel burning in cars.

SO_2 is released into the atmosphere when fossil fuels with sulphur compounds, like coal, oil, and gas, are burned. In addition, some industrial processes that result in the manufacture of paper, metals, and chemicals can also emit SO_2. Fossil fuels sulphur content has recently been reduced, and attempts have been made to implement greener technology to reduce SO2 emissions.

In terms of human health, SO_2 can aggravate already-existing respiratory disorders including bronchitis and asthma. Short-term exposure to high SO_2 concentrations can cause respiratory discomfort, coughing, and breathing difficulties. Children, the elderly, and those with pre-existing respiratory or cardiovascular diseases are particularly vulnerable to the negative effects of SO_2 exposure on their health.

Nitrous Oxide (NO_X): Nitrogen and oxygen combine to form a class of extremely reactive gases known as nitrogen oxides (NO_X). They are formed during combustion processes, and they have a significant negative impact on the environment and air quality. Nitric oxide (NO) and nitrogen dioxide (NO_2) are the two major substances that make up NO_X.

Both natural and man-made sources produce NOx emissions. Biological activity in soils, volcanic eruptions, and lightning are examples of natural sources. The principal causes of anthropogenic NOx emissions, however, are human activity, particularly the burning of fossil fuels. These activities include the creation of electricity, travel (car and aeroplane engines), business operations, and home heating.

When nitrogen and oxygen in the air are burned, they react to generate NOx gases under the high temperature and pressure conditions. A prominent source of anthropogenic NOx emissions is the burning of fossil fuels in cars and power plants. The atmosphere is also polluted by NOx as a result of high-temperature industrial processes like manufacturing, metalworking, and chemical manufacture.

Carbon Monoxide (CO): CO is a colourless, odourless gas that can be harmful if inhaled in large quantities. CO is released when something burns. The biggest sources of carbon dioxide in the surrounding air are cars, trucks and other vehicles or machines that burn fossil fuels. Many items in your home, such as unvented oil and gas heaters, leaky chimneys and furnaces, and gas furnaces, also emit carbon dioxide and can affect indoor air quality. Breathing air with a high concentration of CO reduces the amount of oxygen that can be carried in the blood circulation to critical organs such as the heart and brain. At very high concentrations, which are possible indoors or in other closed environments, CO can cause dizziness, confusion, unconsciousness and death. Very high CO levels are unlikely to occur outdoors. But when CO levels rise outside, it can be especially worrisome for people with certain types of heart disease. These people already have a reduced ability to deliver oxygenated blood to their heart in situations where the heart needs more oxygen than usual. They are particularly sensitive to the effects of carbon monoxide during exercise or increased stress. In these situations, short-term exposure to elevated CO can cause a decrease in oxygenation of the heart, accompanied by chest pain, also known as angina pectoris.

METHODOLOGY

Step 1. Collect required data

- **Emission Source Information:** It includes the location of plywood factory where stack is present and it also include the stack height, diameter, exit velocity and emission rate.
- **Meteorological Data:** Collect the meteorological data for the specific time and location including wind speed, wind direction, temperature, atmospheric stability class, and surface roughness information.

Step 2. Pre-process data

- **Input Data Processing:** Prepare the meteorological data and emission source in an AERMOD-compatible format.
- **Terrain Data:** Prepare terrain elevation and land use data for the modelling domain by using databases of land use and Digital Elevation Models (DEMs), as well as digitizing or importing topographic maps.

Step 3. Set Up AERMOD

- **Model Configuration:** Define the modelling domain, including the study region and receptor locations to assess pollutant concentrations.
- **Source Configuration:** Indicate the details of the emission source, including the height, diameter, exit velocity, and emission rate of the stack.
- **Meteorological Data Processing:** Process the meteorological data to create the necessary meteorological input files required by AERMOD.

Step 4. Run AERMOD

- **Model Execution:** Run AERMOD using the input files and configuration parameters that you have prepared. Pollutant concentrations at receptor locations will be determined using AERMOD, which will model the dispersion of pollutants produced from the source.
- **Plume Rise Calculation:** In order to determine the height to which the plume will rise based on the stated source characteristics and atmospheric stability conditions, AERMOD uses its own proprietary plume rise algorithms.

Step 5. Post process Result

- **Output Analysis:** Graphs showing the plume dispersion pattern and concentration levels at receptor locations should be analysed from the output files produced by AERMOD.
- **Validation:** To evaluate the accuracy and dependability of the modelling outputs, compare the modelled findings with the measured data or reference values that are already accessible.
- **Sensitivity Analysis:** Conduct sensitivity analysis to determine how important input parameters and assumptions affect forecasts of plume rise.

Step 6. Interpret and Report Result

- **Interpretation:** Consider the patterns of pollutant dispersion, concentration levels, and compliance with regulatory standards when interpreting the findings of the modelled plume increase.
- **Reporting:** Make a comprehensive report that includes a summary of the methodology, input data, modelling findings, assumptions, restrictions, and conclusions.

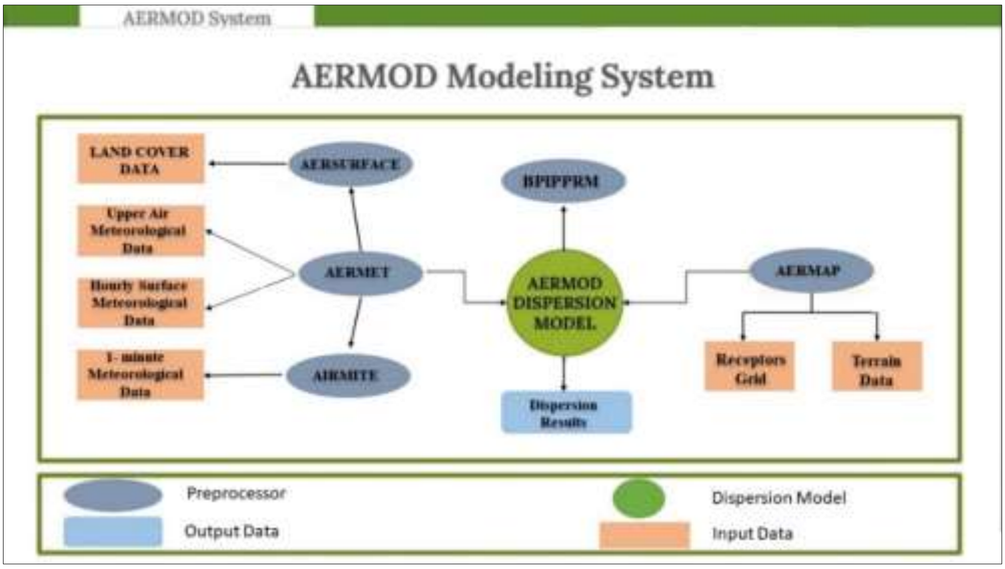


Fig.5: AERMOD Modelling Structure

RESULT & ANALYSIS

Location of factory: The factory is located at Latitude 26.88634°and Longitude 81.05329°, near BBDITM,Lucknow. The factory manufactures plywood and also does veneer finishing. It is functional throughout the year.

Fig.6: Location of plywood factory

Observation virtually done by the software: As there are no observation tool available to us. So we are running it virtually in the software by entering all the necessary details. Our site for observation is Tiwariganj Chauhara and is approx.1700m from the plume. Following are the general concentration of pollutants in Lucknow city, with taking them as reference we are continuing our research.

Pollutants	Concentration
Carbon Monoxide (CO)	741 μg/m^3
Nitrogen Oxide (NOx)	18 μg/m^3
Particulate matter (PM2.5 & PM10)	68 μg/m^3
Sulphur dioxide (SO2)	2 μg/m^3

After finding the values of the required pollutants at our desired site, we are ready to put all of them into the AERMOD. When we compared these values to AQI (Air Quality Index) of Lucknow on any random day we found that most of the values are nearly same. This makes it clear that our researched values are genuine and correct to a greater extent.

Also it gives us a sigh of relief that despite being in a close proximity of a wood industry having a medium size stack we are living in the same environmental conditions as anyone living in a residential area.

Before jumping on to the calculation part we have to put some important parameters inthe AERMOD software so that it can easily identify the atmosphere in which we are operating and will generate accurate results.

So, firstly we have to put the pollutants in a tabular form so that software can read it and understand the frequency with which we are giving data to it i.e. no. of times a person inputs the data.

After providing the frequency of hours, we are able to calculate the pollutant concentration in a whole day. But what if we want the data to be in a form such that it not just only gives daily data but also in form of different seasons as well, here comes another feature of this AERMOD software through which we can enter the pollutants datain different seasons of a year. For e.g. Knowing the pollutant concentration in summer season is a completely different thing if compared to getting it in winter.

Every season has its own temperature and pressure variations which make it different from the other. So, here making another table of pollutants in which we enter concentrations season wise as compared to daily and yearly.

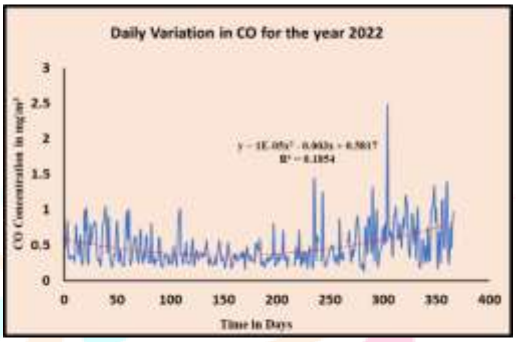
Here we are done with our activities which should be done before jumping in software operations. Now only running and calibration of AERMOD software is to be done.

Then, putting pollutants (CO, $PM_{2.5}$, PM_{10}, NO_X) into the software and finding the location to of desired site into the software. And check on the Monitors, Upper Air and Sources under Display dialogue box.

Run AERMOD using the input files and configuration parameters that you have prepared. Pollutant concentrations at receptor locations will be determined using AERMOD, which will model the dispersion of pollutants produced from the source.

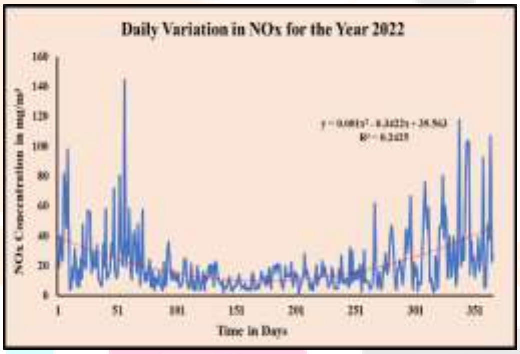
RESULT:

1. **Monthly & Daily Variation of Carbon Monoxide (CO)**



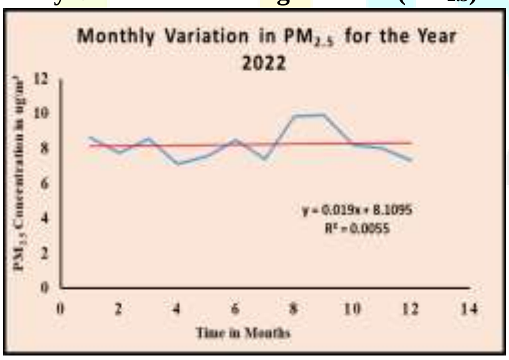
Concentration of CO is minimum in the months of May to July, and is maximum in the winter months of October to December.

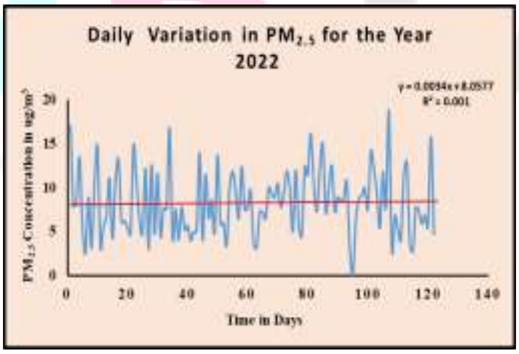
2. **Monthly & Daily Variation of Nitrogen Oxide (NO_X)**



Concentration of NO_X is **minimum in the months of May to June**, and is increases in the winter months.

3. **Monthly & Daily Variation of Nitrogen Oxide ($PM_{2.5}$)**

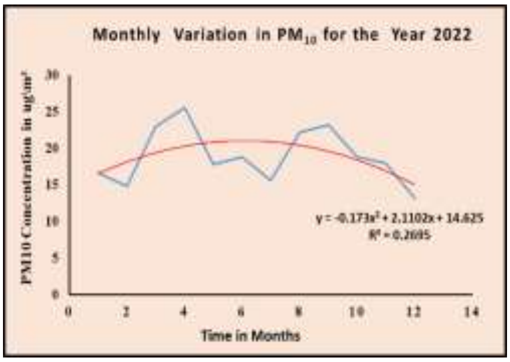


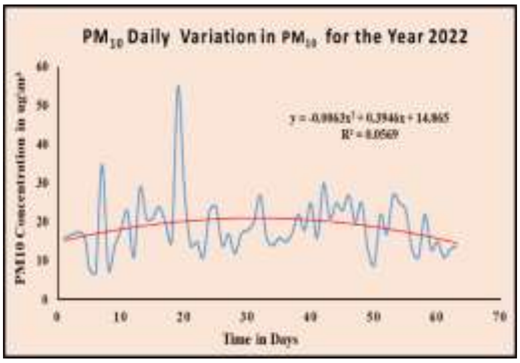


No pattern was perceived in the case of $PM_{2.5}$. This may be due to the fact that in the Indian atmospheric condition, there is a considerable amount of **BACKGROUND CONCENTRATION of $PM_{2.5}$**.

However, a spike in the month of October to November is seen which may be due to many festivals like Diwali, Dussehra where many crackers are burnt.

4. Monthly & Daily Variation of Nitrogen Oxide (PM_{10})





No pattern was perceived in the case of PM_{10}. However, a spike in the month of March to April is seen which may be due stubble burning.
A spike in the month of October to November, which may be due to many festivals like Diwali, Dussehra where many crackers are burnt.

FUTURE SCOPE

The modeling of plume rise using AERMOD, an air dispersion model, has several future scopes:

1. **Environmental Impact Assessments:** The environmental effects of industrial emissions, such as those from industries, power plants, or refineries, can be evaluated using AERMOD. It is possible to forecast the dispersion of contaminants and their effects on the air quality and surrounding receptors by precisely modelling plume rise.

2. **Urban Planning and Land Use Management:** Urban planning and land use management can benefit from the insights that AERMOD can offer regarding the potential effects of new developments, such as roads, airports, or residential areas, on the local air quality. It can assist with developing effective pollution control methods or choosing appropriate sites for future industrial or residential zones.

3. **Emergency Response and Risk Management:** AERMOD can be used to model the dispersion and plume rise of the released compounds during emergency scenarios, such as chemical spills, fires, or accidents involving hazardous materials. Emergency responders can use this information to assess potential dangers to neighbouring communities and to decide on evacuation and containment methods in an informed manner.

4. **Climate Change Studies:** Understanding the distribution and ascent of greenhouse gas plumes is essential as the effects of climate change become more significant. AERMOD can be used to model the dispersion of carbon dioxide (CO2) and other greenhouse gases from various sources, assisting in the assessment of their regional and global contributions to climate change.

5. **Renewable Energy Planning:** AERMOD can support the development and installation of renewable energy infrastructure such as wind farms and solar panels. Modelling the rise and spread of air pollutant plumes can help determine the best locations for such projects, given their potential impact on air quality and nearby sensitive areas.

These are just a few examples of future possibilities for modelling plume rise using AERMOD. As technology advances and environmental concerns grow, the application of air distribution models continues to expand, providing valuable insights into environmental management, public health, and decision-making.

CONCLUSION

- This project presents the concept of change of concentration and variation in level of pollutants in a stack plume of a plywood industry, located in Semra, Lucknow.
- Four pollutants viz. CO, NO_X, $PM_{2.5}$ and PM_{10} was analyzed by using AERMOD Dispersion Model.
- After doing a series of rigorous analysis, it was found that the trend in variation of CO and NOx is almost similar, but at the same time it is different for $PM_{2.5}$ and PM_{10}.
- For CO and NOx concentration is increasing in winter and decreasing in summer, and for $PM_{2.5}$ concentration is not clearly observable, for PM_{10} also no visible trend is observed.
- Main reason behind increase and decrease of concentration was due to excess pressure and low temperature and were in a downfall in summer due to low pressure and high temperature as well as high wind speed.

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