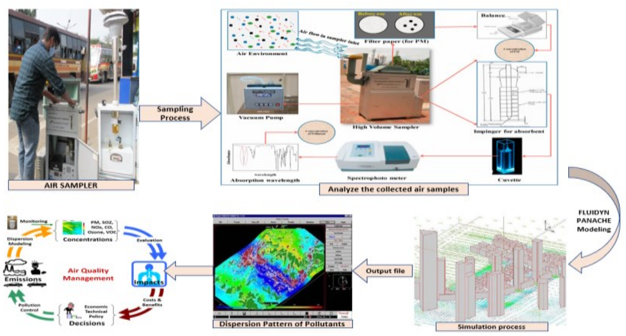
Global NEST Journal, Vol 25, No 5, pp 66-75

Analysis of seasonal variation and dispersion pattern of ambient air pollutants in an urban environment

Sadheesh S.[1] and Jeyanthi J.[2]*
[1]Department of Civil Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India
[2]Department of Civil Engineering, Government College of Technology, Coimbatore, India
Received: 22/12/2022, Accepted: 10/02/2023, Available online: 14/02/2023
*to whom all correspondence should be addressed: e-mail: sadheesh01@gmail.com
https://doi.org/10.30955/gnj.004670

Graphical abstract



Abstract

The level of air pollution increased in urban areas due to local atmospheric conditions and dispersion of various air pollutants. In this study, the air quality index was carried out in four places in the urban zone and investigated the seasonal variation of $PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3 over one year (2021) by considering the meteorological parameters in Coimbatore. Furthermore, fluidyn-PANACHE, a CFD tool, has been used to simulate the dispersion pattern of gaseous pollutants in the selected locations. To track the model, the concentration details of gaseous pollutants were collected and pollutant dispersion under numerous atmospheric conditions (Humidity, Temperature, Pressure). was identified using fluidyn-PANACHE software. From the collected air samples and dispersion pattern, SO_2 and O_3 show higher concentrations in summer. Particulate matter and NO_2 show higher concentrations in winter due to seasonal variations in energy use and atmospheric constancy. Pearson correlation coefficients indicate most pollutants are correlated in Coimbatore except Ozone. Compared to the AQI category given by CPCB, the selected four locations are in the moderate category. However, increased PM_{10} levels were observed at all the selected zones in winter due to the process of inversion and environmental conditions.

Keywords: Particulates, fluidyn-panache, dispersion, air samples, inversion, pearson coefficient.

1. Introduction

As per World Health Organization (WHO) description, air pollution releases undesirable substances into the atmosphere that are detrimental to humans and the environment. The environment has a limited pollutant assimilative capacity, beyond which it becomes polluted. Poor air quality is one of the world's foremost risk factors for death, respiratory problems, and human disorders; WHO estimates around seven million deaths occur yearly due to air pollution. The pollutants emitted from industries, vehicles, and human activities reach the ambient air, and the pattern of pollutant movement was controlled by existing infrastructures, nature of work, habitat of people, and rules and regulations followed in industries. Air pollution levels may vary from one place to another in the same region concerning various conditions and parameters due to anthropogenic activities like the release of unwanted industrial gases, mining, use of chemical fertilizers, pesticides, stubble burning, incineration of fossil fuels, and deforestation results in changes to the climatic pattern, biodiversity, ecosystem, and poor air quality. The level of air pollution may be altered by human activities, local conditions, and climatic patterns (Bodor *et al*., 2020). The results validate that existing weather conditions, movement of vehicles, and industrial emissions (or surrounding activities) play a remarkable part in spreading airborne particles. Accumulation of air pollutants, both particulate matter and various gaseous pollutants, were predicted by the proposed ICEEMD-ISCA-LSSVM model and has been widely studied (Li *et al*., 2019). For monitoring of pollutants correlation analysis (COA), principal component analysis (PCA), and cluster analysis (CLA) methods are used for identifying monitoring stations in an air quality monitoring network (AQMN), all the methods are used to improve the accuracy of air pollution monitoring in selected locations (Wang *et al*. 2018). Gated Recurrent Units (GRU), Recurrent neural networks (RNN), and long short-term memory (LSTM) networks are used to predict the air quality level and estimate the PM_{10} concentration pattern by deep learning models (Athira *et al*., 2018). The raise of structure orientation and heat stratum suggestively disturb the airflow pattern in and around the buildings

(Huang *et al*., 2021). Fluidyn-PANACHE is used to examine the impact of tall structures on the movement and dispersion of pollutants under stable atmospheric conditions. The height of the structures, site selection, and temperature stratum variation certainly disrupt the pollutant dispersion pattern. When examines various research about the evolution of air pollution management policies by gathering data from the earlier studies compiled in a computer-generated repository called IndAIR (Gulia *et al*. 2022). Quality of air is very important, and it is considered one of the life-threatening problems for urban residents and remains the main cause of death worldwide. Industrial and vehicular growth increases local air pollution, especially in the urban atmosphere. The air impact assessment study is considered one of the utmost essential factors of transportation projects. Collected field data, modern software tools, and digital measurements by sensors are used in analyzing the current range of air quality in several states and conclude the origin of pollution and method of contamination are intertwined (Guttikunda *et al*. 2014). Comparing all other segments, emission from the transport sector is the supreme perilous and farthest connected in the systematic, judicial, economic, and institutional framework of the 112 openly available clean air action plans submitted under NCAP and executed a wide-ranging Programme for the prevention, control, and reduction of pollution (Ganguly *et al*. 2020).

The air quality level of Coimbatore decreases due to its rapid manufacturing development and urbanization. Change in climate influence the altitudinal and sequential variation of air pollution; the foremost air pollutants considered are particulates, oxides of sulfur & nitrogen, and ozone. By this precise, the current research focuses on assessing the outdoor pollution level in four significant areas. Each urban area has its own set of methods and ratios for measuring pollution. As per the Pollution control board, the major air pollutants are Particulate matter, Oxides of Sulphur, Carbon & Nitrogen, and Ozone. The range of air quality index (AQI) is calculated from the collected pollutant data, and the ranges were related to NAAQS (Meenakshi and Elangovan 2000); the dispersion pattern of gaseous pollutants has been carried out concerning pollutants concentration under critical wind speed computed by the gaussian dispersion model. It is usually recognized that a computational fluid dynamic model would afford practically moral solutions to categorize the flow of wind in and around the industries. For checking the dispersion pattern of pollutants in the selected zones, a practical Computational Fluid Dynamics (CFD) model fluidyn-PANACHE is instigated to check the dispersion of air pollutants in the selected site. Inter-correlation and dispersion pattern of chemical gases are considered for analyzing the proper air quality status in the city.

2. Materials and methods

2.1. Site description

Coimbatore (11.0168° N, 76.9558° E) is located at a raise of 411 meters from sea level. Air samples are collected at four locations in the city: Gandhipuram, Ganapathy, Singanallur, and Sundarapuram, which come under commercial, residential, traffic, and industrial sites, respectively, as shown in Figure 1. To check the air pollution level in the various zones of the city, collected one-year samples were assessed and analyzed for major criterion pollutants in the selected four zones. The concentration of particulate matter and gaseous pollutants were obtained from the experimental work carried out in this study (Goyal *et al*., 2021). From the experimental analysis, AQI values have been calculated. The air quality index defines the general air quality in a particular zone to the public; by this AQI range, people can easily know the current air quality status. The following reference methods have been used for analyzing the pollutants:

- Particulate matter by gravimetric method
- Sulfur dioxide by UV fluorescence
- Oxides of nitrogen by chemiluminescence
- Ozone by UV photometry

The total concentration of particulate matter is estimated by weighing the filter paper and the quantity of pollutants collected in the filter paper. The concluding values are expressed in terms of μg/m^3.

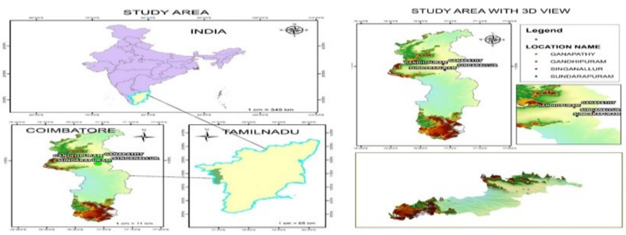


Figure 1. Location of sampling sites

For the analysis of dispersion patterns, fluidyn-PANACHE modeling software is used to check the pollutant dispersion in the portion of a city under various meteorological conditions. CFD model fluidyn-PANACHE used to study the dispersion of air pollutants in the selected locations under various parameters has been studied (Bhakiyaraja S *et al*., 2016). The details of the sampling area, direction, and coordinates of the location are mentioned in Table 1. Study areas were categorized based on the nature of the site and development as residential, commercial, traffic, and industrial zone.

Table 1. Study area information

S. No	Site name	Site type	Latitude	Longitude
1	Ganapathy	Residential	11.04	76.98
2	Gandhipuram	Commercial	11.02	76.96
3	Singanallur	Traffic	10.99	77.03
4	Sundarapuram	Industrial	10.96	76.97

2.2. Monitoring and sampling

Monitoring and sampling of pollutants: PM_{10}, $PM_{2.5}$, SO_2, NO_2, and O_3 was carried out from Jan 2021 - Dec 2021 shown in Figure 2. This study analyzed the air pollutants level and air quality index of four sites in Coimbatore. Atmospheric conditions and meteorological details were obtained from the continuous ambient air quality monitoring station of the pollution control board.

Figure 2. Instruments used in sampling

A Respirable dust sampler (Envirotech APM 550M) was used to collect particulate matter for both $PM_{2.5}$ and PM_{10} and a gaseous pollutants sampler (Envirotech APM 433) was used to collect gaseous pollutants. On all sampling days, 24 hrs samples were collected for PM, NO_2 & SO_2 and 8 hrs samples were collected for ozone as per (CPCB 2009). PM samples are collected in filter paper and gas samples are absorbed through impingers filled with absorbent. The filter papers were placed in a desiccator before and after sampling prior to weighing under room temperature 27°C to remove moisture. Weighing of filter papers was done using microbalance Filter papers are weighed twice before and after sampling to maintain quality control. During monitoring, a constant sampling flow rate of 16.7 lpm should be maintained and the choking of filters checked by the orifice system (CPCB 2011). The dust particles were collected at a height of a minimum of 10 feet on the roadside. The mass of collected air samples was estimated gravimetrically and filter papers were weighed before and after sampling on an electronic microbalance and stored at -10 to 20 ◦C and shielded by aluminum foils till the process of chemical analysis as per the guidelines given by the United States EPA. When compared to PM_{10}, handling filters for $PM_{2.5}$ analysis is critical. Once the sampling time is over, filters must immediately be removed from the instrument and shielded properly. For measuring Oxides of Nitrogen and Oxides of Sulphur, separate Impingers were used in the Respirable Dust Sampler. Oxides of sulphur and Nitrogen is determined by reacting the exposed absorbing reagent with Sodium Tetracholoromercurate and Sodium Hydroxide at 540nm.The meteorological data such as temperature, humidity, wind speed, wind direction, rainfall pattern, and barometric pressure are noted concurrently. For predicting pollutant concentration models are also used in various research, especially the MTD-CNN-GRU model performs best at the time of high fluctuations and unexpected variations in the data due to the presence of convolutional layers and gated recurrent unit layers (Zhang *et al*., 2020). For analysis, baseline data like vehicle count, type of vehicle, industrial type, and several industries were considered as reference parameters at the observing site at the time of sampling. An AQI is an overall index of air that defines the general air level in the public domain; common people can easily understand AQI. Fluidyn Panache was also investigated to observe the dispersion pattern of pollutants in the selected location. Fluidyn Panache also considers the impact of various topographical features, climatic conditions, and wind patterns in the selected site. An air quality monitoring networks (AQMN) method for finding redundant monitoring sites using various correlation analyses, principal components analyse, and cluster analyses (wang *et al*. 2018). low-cost sensors are identified for collecting spatial and temporal data, and a dispersion model is used to test the dispersal of dust particles in a range of 10µm measured by several distinct points of the network (Sofia *et al*. 2018, Kortoçi *et al*. 2022).

2.3. Modelling using fluidyn atmospheric dispersion software

The CFD model, specifically Fluidyn-PANACHE has been used in the present study for numerical simulation of atmospheric pollutant dispersion and air quality prediction. This software is entirely based on a 3D-CFD approach (Computational Fluid Dynamics); this modeling tool can predict high accuracy in near and far fields. Various modes like physical, statistical, empirical, and deterministic models are used in Fluidyn Panache software. Inspecting the reason for the scattering of impurities that highly occurred on the highway by CFD modeling and outcomes found by LES validate the behavior of plume dispersion pattern in the street canyon is unstable and unsteady (Tominaga *et al*. 2011).

2.4. Model characterisation

For dispersion phenomena, some factors to be considered are emission type, transport dispersion, transformation to ambient air, and source of pollutants (line or point). The present study aims to predict the maximum ground-level concentration and dispersion pattern of NO_2, SO_2, and O_3 in the neighbourhood of the selected location in Coimbatore. Input requirements needed for this dispersion modeling software are listed as i) release characteristics, mainly temperature of pollutants, ii) meteorology factors for checking convection/advection and turbulent diffusion (random) iii) properties of species for molecular diffusion. Meteorological forces are:

- Horizontal wind speed and direction.
- Atmospheric stability.
- Vertical motion is induced by flow and terrain.

Fluid-Panache, a computer model related to the RANS technique useful to predict pollutant dispersion and airflow pattern (Gao *et al*., 2021). To reduce environmental impact in urban infrastructure by suitable planning options and 3D modeling process through the appropriate implementation of cleaner and sustainable solutions (Casazza *et al*. 2019).

2.4.1. Model parameters

In CFD modeling, numerical integration of the governing equations and conservation laws are used in grid and boundary conditions. Terrain definition (altitude curve, obstacles, importing GIS, trace over a map), physical description, wind, and source condition have been given as input data for mesh generation. 3D mesh (Figure 3) and proper digital terrain details (buildings, curves, road pattern, forest, nature of the terrain, urban source: line, point, area, geometry) are needed for running the simulation and analyzing the result. Physical models are mostly used for incompressible fluid or light gases like SO_x and NO_x; these models relate to the governing equation and underlying physics. In examining the analytical performance of the computational fluid dynamics (CFD) model - Fluidyn-PANACHE, the effect of atmospheric stability in street canyons under various flow conditions is analyzed (Guo *et al*. 2020). The results prove that once atmospheric conditions are constant, the upright profile of the streamwise velocity is deliberately reduced by the obstacles, and pollutant dispersion increases. The salient topographical features are imported into PANACHE for terrain model setup. An ideal mesh size has been created for the study by considering the topography and the Source locations. The dispersion pattern has been carried out concerning selected pollutant concentrations. Air quality assessment and sampling were carried out in various places of Coimbatore and modeling software's artificial neural network and caline 4 network models were used for the prediction and dispersion pattern of air pollutants in the selected locations (Sadheesh *et al*., 2019)

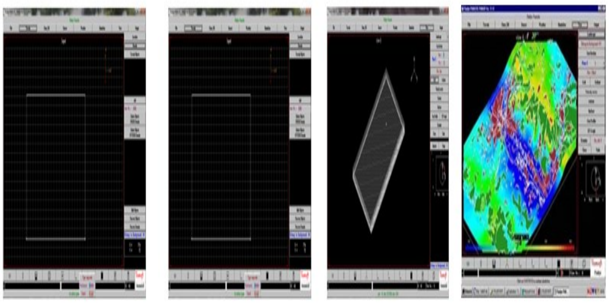


Figure 3. View of the computational mesh

3. Results and discussions

3.1. Annual concentration of pollutants

The association between climatic conditions and atmospheric pollutants was assessed using regular monthly values. Annual concentrations and monthly differences of the various pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3) during the year 2021 in the selected location of Coimbatore are presented in Figure 4. From the results obtained, a clear periodic difference was detected. Burning of biomass can contribute highly in the winter when compared to the monsoon season and the extensive rainy season pattern similarly supports the effective spreading of contaminants in the particular region (Aswini *et al*. 2018). therefore, Carbonaceous aerosols contribution range varies from 30% to 60% on a seasonal basis. Both particulates and gaseous pollutants collected and observed data are shown in Figure 3. It shows the seasonal variation of major pollutant concentrations in Coimbatore's selected 4 monitoring zones. Ganapathy, which comes under the residential zone, the Concentration of $PM_{2.5}$ ranges from 56.4 to 82.6 μg/m^3, PM_{10} concentration varies from 72.7 to 109.6 μg/m^3, NO_2 concentration ranges from 29.5 to 39.8 μg/m^3, SO_2 concentration ranging from 20.2 to 28.7 μg/m^3, Ozone concentration ranging from 24.4 to 37.7 μg/m^3. Singanallur, which comes under the traffic zone, Concentration of $PM_{2.5}$ fluctuating from 68.6 to 90.4 μg/m^3, PM_{10} concentration ranging from 71.5 to 108.6 μg/m^3, NO_2 concentration ranging from 30.6 to 43.5 μg/m^3, SO_2 concentration ranging from 20.6 to 31.2 μg/m^3, Ozone concentration ranging from 25.3 to 40.9 μg/m^3. Gandhipuram, which comes under the commercial zone, $PM_{2.5}$ concentration ranging from 63.7 to 93.6 μg/m^3, PM_{10} concentration ranging from 82.4 to 110.8 μg/m^3, NO_2 concentration ranging from 32.7 to 43.3 μg/m^3, SO_2 concentration ranging from 21.9 to 36.3 μg/m^3, O_3 concentration ranging from 27.2 to 41.8 μg/m^3. Sundarapuram, which comes under the industrial zone, the Concentration of $PM_{2.5}$ varies from 55.8 to 81.4 μg/m^3, PM_{10} concentration ranges from 81.2 to 121.8 μg/m^3, NO_2 concentration ranges from 30.6 to 41.2 μg/m^3, SO_2 concentration ranging from 27.5 to 42.6 μg/m^3, O_3 concentration ranging from 25.8 to 38.2 μg/m^3. NO_x and CO exposed peaks during peak traffic hours and a valley in the noon time irrespective of the seasons; the hourly averaged mean SO_2, NO_x, CO, and O_3 concentrations during the study period ranged from 0.6 ppb to 97.9 ppb, 0.5 ppb to 95.6 ppb, 39 ppb to 4987 ppb, and 1.2 ppb to 112.6 ppb, respectively, with a mean and one standard deviation of 2.9 ± 3.2 ppb, 6.1 ± 5.1 ppb, 696 ± 398 ppb, and 28.1 ± 18.1 ppb, respectively (Abhishek Gaur *et al*. 2014). To derive a correction formula to account for this temperature dependence while quantifying the emissions from roadside traffic in Norway and concluded observed NOx concentration observed in site and transport modeling EMEP/uEMEP software prediction are the same (Waersted *et al*. 2022). Therefore, elevated levels of $PM_{2.5}$ and PM_{10} have a significant effect on human well-being and the atmosphere, examination using a suitable risk analysis should be carried out in upcoming studies. Compared with other pollutants, the concentration of O_3 detected in a different pattern (O_3 values recorded maximum during the summer) exhibited a substantial association with temperature and humidity. The research work was carried out at the time of the pandemic period so the movement of vehicles is lower than normal time hence comparison with the previous year's data leads to some differences in pollutant range. Ozone is a relatively stable molecule, only at high ozone concentrations and elevated temperatures does it decompose to oxygen at a significant rate (Cotton and Wilkinson, 1980). By chemical analysis method (UV photometric Chemiluminescence) concentration of ozone can be measured and analyzed.

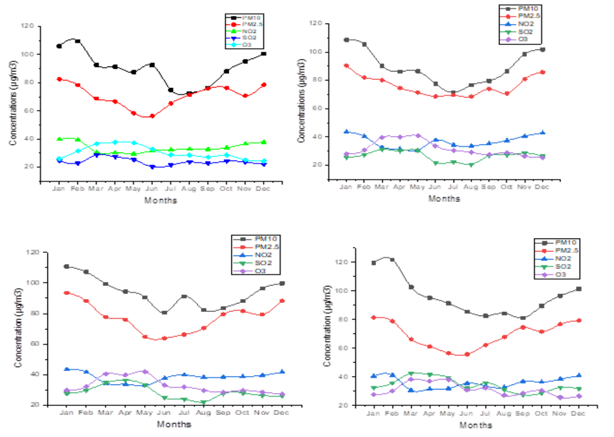


Figure 4. Monthly variation of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 concentrations in (a) Ganapathy, (b) Singanallur, (c) Gandhipuram, (d) Sundarapuram

3.2. Variation in pollutant concentration due to meteorological factors

The significant factors that normally influence pollutant concentrations are climatic factors, including temperature, wind speed, humidity, and atmospheric pressure. Monthly average values for major air pollutants and meteorological influences were determined throughout the study period in Coimbatore, shown in Figure 5. A proper seasonal pattern was observed for temperature, wind speed, humidity, and atmospheric pressure.

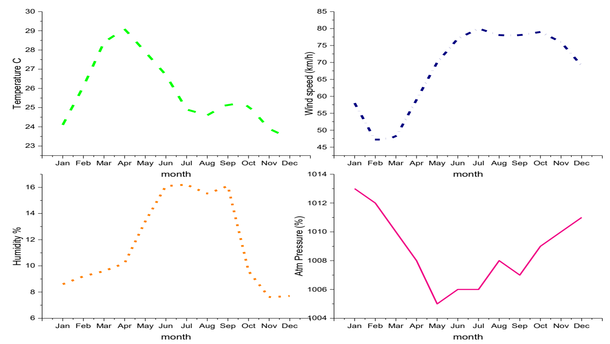


Figure 5. Monthly variation of Temperature, wind speed, humidity, and atmospheric pressure

In Coimbatore, the normal temperature of the coldest month is 24 °C, that of the warmest month is 30 °C, and wind speed varies from 7 to 16 km\hr., Humidity ranges from 47 to 79 %; Atmospheric pressure varies from 1005 to 1014 mbar. Rainfall data varies from 520 to 910 mm. Planned minimal budget monitoring system for pollutant identification using microcontroller chips and small sensors like MW125, NX142, and HRC154 are used for detecting various harmful pollutants ammonia, methane, sulfur, and carbon. Sensors detect some parameters like temperature, humidity, location of pollutant emission, and concentration of pollutants and analyze the result on digital maps to give the air quality status to responsible agents who can monitor the sources of contaminants in the selected area, the scheme similarly records the output on a specific platform (Talib *et al*. 2021). Considering the seasonal variation of air pollutants in Coimbatore and the results showed changes in meteorological parameters directly influence the concentration and dispersion of pollutants in all the seasons (Meenakshi *et al*. 2013).

3.3. Association among pollutants and site conditions

The complete monthly concentrations and comparison of all criteria pollutants: $PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3, are shown in Figure 6. The pollutant concentration slightly varies from month to month and pollutant concentration level was compared with National ambient air quality standards in all the selected zones. In this study, four locations have been analyzed concerning pollutant sources in the study area. To authenticate the spatial and monthly difference in air pollutants, a statistical study was carried out for validation. Variations of pollutants are due to emission sources, dispersion patterns, or the accumulation process in the atmosphere under different conditions. The emission of pollutants changes concerning location based on the nature of the place and surrounding environment. Beijing's air pollutant status has been investigated, and it concluded accumulation of pollutants is due to wind patterns, humidity, and temperature (Guo *et al*. 2017). Good air quality was observed at the time of maximum wind and minimum humidity. In industrial zones, both SO_x & PM_{10} emission and dispersion rates were higher when compared to residential or commercial zones, but $PM_{2.5}$, NO_x, and O_3 emission and dispersion rates highly occurred in commercial places due to various construction activities and movement of vehicles. The NO_2 emission rate is generally higher in the traffic zone in this study. Also, the emission of NO_2 in Singanallur is high because of the movement of automobiles. All the major pollutants like SO_2, NO_2, $PM_{2.5}$, PM_{10}, and Ozone were recorded slightly lower in Ganapathy (Residential zone), but $PM_{2.5}$ and PM_{10} exceeded the limits prescribed by the pollution control board. The relation between atmospheric levels of various pollutants and variation in temperature do affect human health and cause respiratory problems was examined (Freitas *et al*., 2010). Traffic emission and vehicular contribution are considered the major source of PM_{10} Concentration in most areas (Grivas *et al*. 2004).

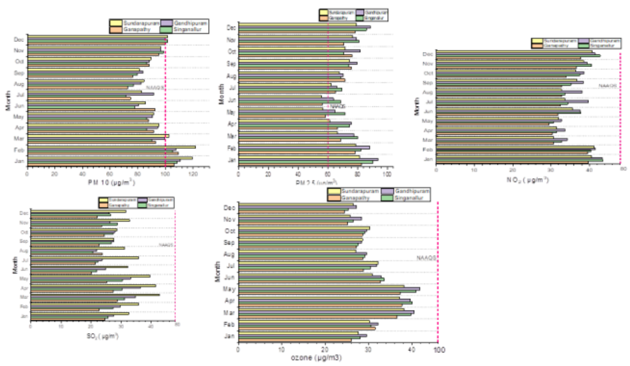


Figure 6. Monthly variations and comparison of pollutants with NAAQS

3.4. Seasonal variation of ambient pollution

The seasonal variation and progression of the monthly values are obtained in this study. The variation in particulates and gaseous pollutants during one year in various seasons is evaluated using statistics and shown in Figure 7. Investigating the seasonal ratio aspects of particulates and gaseous pollutants. The annual average peak concentration of Particulate matter was observed during the winter ($PM_{2.5}$ 93.6 and PM_{10} 123.1 μg/m^3, respectively), and minimum concentration was observed in the monsoon ($PM_{2.5}$ 55.8 μg/m^3, PM_{10} 71.5 μg/m^3) especially PM_{10} value increased in weekends with low wind speed. However, in all seasons, $PM_{2.5}$ and PM_{10} levels exceeded the NAAQS recommendation limit of 60 μg/m^3 and 100 μg/m^3. Seasonal variation, vehicular emission, meteorological conditions, and agricultural activities are considered factors for the variation of pollutants during the entire year. Contaminant concentration was observed higher in the industrial cluster followed by the vehicular zone. The relatively highest mean absorption of ozone (2.31 ± 0.80 μg/m^3) and oxides of carbon (8.1 ± 1.91 mg/m^3) were noted during the midsummer time (Manju A *et al*. 2018), while the level of PM_{10} (79.9 ± 25.1 μg/m^3), $PM_{2.5}$ (44.8 ± 18.0 μg/m^3, SO_2 (8.12 ± 1.62μg/m^3) and NO_2 (12.9 ± 1.79 μg/m^3) was maximum during the southwest monsoon. Ozone and oxides of Carbon are interrelated with temperature and are undesirably associated with relative humidity. Investigation of spatial-temporal variations of air pollution monitoring data in Ireland recently concludes COVID-19 restrictions reduced the air pollution level in urban areas all over the world and led to variation in traffic-related air pollution (Perillo *et al*. 2022).

The maximum concentration of SO_2 (42.6 μg/m^3) was observed during the pre-monsoon season (Mar, Apr, and May) in the industrial zone, followed by the commercial and residential zone. Still, in all the selected zones levels are within the NAAQS guideline value of 80 μg/m^3. The climatic situations in summer were typically related to the temperature variation and extended time of strong sunbeams (Gaur *et al*. 2014). The seasonally averaged diurnal variation of SO_2 is noticeable in winter, especially during traffic hours because of the comparatively low mixing height. Analyzing the concentration of NO_2, the maximum concentration of 43.9 μg/m^3 was observed during winter, followed by the northeast monsoon in commercial and traffic zone respectively. The highest NO_2 was recorded in winter due to fossil fuel burning in domestic activity and vehicular emissions A huge amount of nitrogen dioxide was released into the atmosphere through combustion, welding, explosives, food, and commercial manufacturing. $PM_{2.5}$ is responsible for poor air quality in some places of China. Compared to other pollutants, ozone showed a negative correlation due to various factors like power plants, stubble burning in that study area leads to increased air pollution (Yungang Wang *et al*. 2014).

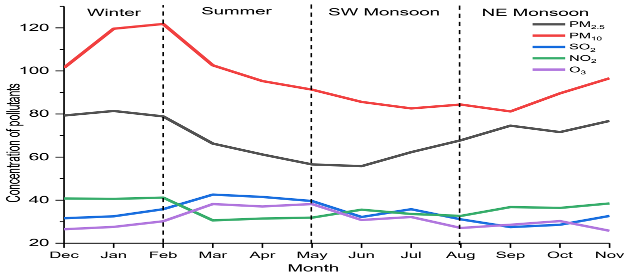


Figure 7. Seasonal variation of pollutants.

Figure 7 shows the variation in ozone concentration among different seasons in all the selected locations. The maximum concentration of O_3 41.8 μg/m^3 was recorded in the summer season, and a minimum concentration of 23.2 μg/m^3 has been observed in winter and post-monsoon season, especially in November and December; quicker daytime periods and more planetary zenith angles during winter might be responsible for lower ozone concentration. Investigation of the daily, weekly, and monthly seasonal variation of ozone, oxides of nitrogen, volatile organic compounds, and the relationship among weather patterns and climatic conditions in Barcelona final results showed various chemicals like formaldehyde, methanol, isoprene, and acetone influence the highest ozone formation potential at the time of research (Filella *et al*. 2014, Gaur *et al*. 2014). Recently reported, around 49% of the world's 1.3 billion population are exposed to contaminants that exceed the WHO maximum air quality threshold of 35 μg/m^3. However, an additional 12% and 19% are exposed in the ranges 24-34 and 16-24 μg/m^3 consistently (dey *et al*. 2012). Multiple pollutants are responsible for increased air pollution in the selected location; different seasons and zones reflect the various divergences among air pollution. Region-wise comparative studies, source identification, and a suitable method of planning are highly recommended; this research demands upcoming work to explore the relations among the level of pollutants, AQI range, and conversion of chemicals present in air by the physicochemical process also increases the air pollution level in Coimbatore.

Table 2. Pearson's correlation coefficient between pollutant and meteorological parameters

	$PM_{2.5}$	PM_{10}	SO_2	NO_2	O_3	Temperature	Windspeed	Humidity	Pressure
$PM_{2.5}$	1								
PM_{10}	0.89	1							
SO_2	0.54	0.6	1						
NO_2	0.79	0.71	0.52	1					
O_3	0.09	0.11	0.27	-0.18	1				
Temperature	-0.16	0.18	0.04	-0.26	0.65	1			
Wind speed	-0.26	-0.32	-0.14	-0.33	-0.06	-0.17	1		
Humidity	-0.13	-0.18	0.21	-0.13	0.02	0.17	-0.11	1	
Pressure	0.06	0.08	0.41	0.35	-0.71	-0.92	-0.51	-0.09	1

The influences of various pollutants and meteorological parameters are studied. Most of the air pollutants are negatively correlated with meteorological conditions due to the accumulation and dilution of air. A positive correlation among major pollutants particulates, SO_2, and NO_2 can be realized irrespective of the season of the year (Table 2). Ozone negatively correlated with oxides of nitrogen. All the parameters like temperature, wind speed, humidity, and atmospheric pressure correlation have been identified by Pearson's correlation coefficient. PM_{10} was negatively correlated with wind speed ($r = -0.51$, $p < 0.002$). In addition, CO 8hr and NO_2 were highly correlated ($r = 0.59$, $p < 0.001$) representing that the main source of their emissions originated from transport (Grivas *et al*., 2004). The meteorological parameters and vehicle traffic volume influencing the mass concentration of PM were analyzed through Pearson correlation analysis.

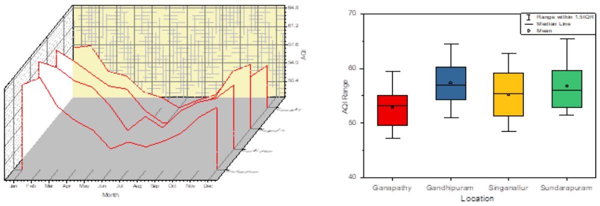


Figure 8. Range of AQI from Jan to Dec 2021

3.5. Relationship between AQI and pollutants

AQI tells the air quality in the specific location and the associated impacts of the worst air condition on that selective zone. Generally, AQI ranges from 0 to 500. The utmost significant figure on the scale is 100 because it corresponds to the moderate category in NAAQS. So, the AQI range of less than 100 is understood to be satisfactory. When AQI values increase, more than 100 denotes air quality is considered detrimental. Various color codes denote air quality, like green, yellow, orange, red, purple, and maroon. Each color represents the range of Air Quality Index Values. Recently government agencies easily communicate air quality to the public by displaying AQI values on the digital board at important places in major cities so that people can get some awareness about air quality. Category of AQI and obtained result also reveals moderate air pollution was observed in all the sites except the industrial site and air quality index range is normally maximum in winter shows high air pollution and minimum during monsoon reflects air quality in a satisfactory condition (Saravanakumar *et al*. 2016).

In the current research, the air quality index (AQI) was calculated by considering all five criteria pollutants; $PM_{2.5}$, PM_{10}, SO_2, NO_2, and O_3. An AQI is a normal value that easily defines the status of air to the public. In the selected location of Coimbatore: Ganapathy, which comes under the residential zone, the range of AQI varies from 47 to 60; Singanallur, which comes under the traffic zone, the range of AQI varies from 48 to 63; Gandhipuram, which comes under commercial zone the range of AQI vary from 51 to 65, Sundarapuram which comes under industrial zone the range of AQI varies from 52 to 66. The range of AQI levels is noted, and diagrams in Figure 8 represent their variations. The station-wise variation of AQI values during the year with medians, means, ranges, and lower and upper limits are depicted. During the study period, from the selected four locations, the AQI value was recorded lower in the Ganapathy area, which comes under the satisfactory category because all the selected pollutants SO_2, NO_2, O_3, $PM_{2.5}$, and PM_{10} are recorded slightly lower than the other location. Annual $PM_{2.5}$ data observed in the study was above the NAAQS standard limits for all four locations, and PM_{10} exceeded the standard limits only during the winter season in the selected sites. AQI value is recorded higher in the Sundarapuram area because industrial clusters, especially PM_{10} and SO_2, exceed the limit because of industrial emissions. Normally AQI ranges higher in winter (Dec, Jan, and Feb) because pollution level is normally higher due to the colder climate and inversion process; cold air traps pollutants close to the ground, so pollution level is higher this season. The various pollutant physical characteristics and their association to multi-scale atmospheric conditions concluded atmospheric conditions were more contrary to pollutant distribution representing that the development in air quality was instigated by emission controls (Jianjun *et al*. 2017).

3.6. Dispersion pattern

Fluidyn Panache software is used to predict and analyze the dispersion pattern of urban air pollutants from a small scale to a large scale. The following pollutants are considered in the study: SO_2, NO_2, and O_3. FLUIDYN- PANACHE uses the following parameters: location map, pollutant concentration, meteorological parameters, molecular weight, and molecular diffusion coefficient. Dispersion pattern in 2D and 3D view has been evaluated from the Fluidyn panache model. Various color codes like blue, green, yellow, and red show the concentration and distance of the dispersion pattern. Blue color indicates minimal pollutant concentration and dispersion on that site; green color indicates medium dispersion, and red color indicates maximum dispersion pattern. Dispersion of pollutants mainly depends on concentration, terrain map, wind movement, temperature, and topography of the study area. The real-time dispersion pattern of a particular area has been analyzed for point and non-point sources; for a point source, we need to fix the geometry (dimensions, tilt XY angle) and simulate the model with identified background concentration of the selected zone. At the time of simulation, we need to fix the proper scale for accuracy of the output file, mostly that precision denoted by E. If we fix E=10 means the dispersion pattern and simulation can be completed earlier, but the level of accuracy is medium. For higher accuracy in the isometric projection, fix E = 1000, but completion of the simulation, it takes more time. Concerning the Fluidyn-PANACHE Technical Manual, 2009 fixing of E value, map tracing, importing a GIS file, and 3D mesh generation at the time of modeling was an important task in this modeling tool. Before 3D mesh generation in a physical model, one should identify the gas type:

compressible (SOx, NOx) or incompressible (NH_3, Cl). Gas pollutant dispersion pattern depends on atmospheric stability, air temperature, surface temperature, and horizontal wind. In this work, the atmospheric condition has been considered neutral for simulation purposes. The output file denotes the maximum dispersion of SO_2 that occurred in the industrial zone shown in figure, the maximum dispersion of NO_2 in the commercial zone followed by the traffic zone shown in Figure 11; Higher O_3 dispersion pattern shown in the traffic and commercial zone. Based on the meteorological parameters, terrain nature, source type, species property (molecular diffusion), and terrain features (Buildings, curves, road pattern, and forest), the dispersion pattern varied accordingly. Dispersion patterns of gaseous pollutants SO_2, NO_2, and O_3 in all four zones are plotted using Fluidyn – Panache modeling shown in Figures 9, 10, 11 and 12 respectively. Figure 9 denotes pollutants dispersion in traffic zone where NO_2 and O_3 dispersion rate are shown to be higher than SO_2. Figure 10 indicates the dispersion rate of O_3 was higher than SO_2 and NO_2 in a residential zone. Figure 12 denotes $S0_2$ dispersion rate is higher than the other two pollutants.

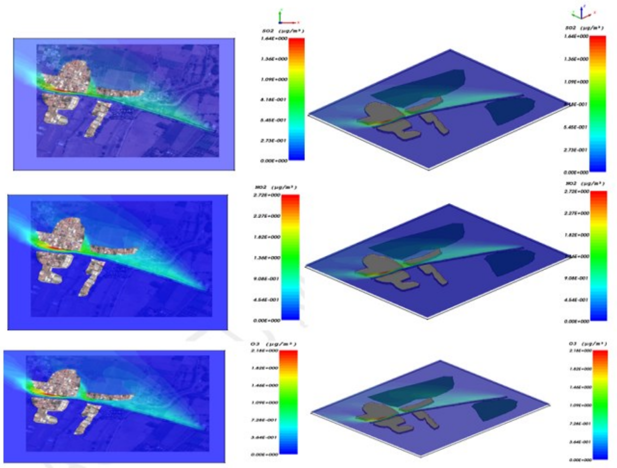


Figure 9. Represents the 2D and 3D views of pollutant dispersion in a traffic zone

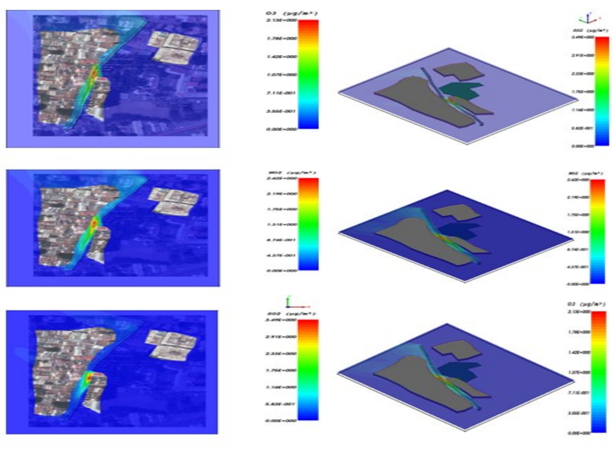


Figure 10. Represents the 2D and 3D views of pollutant dispersion in a residential zone

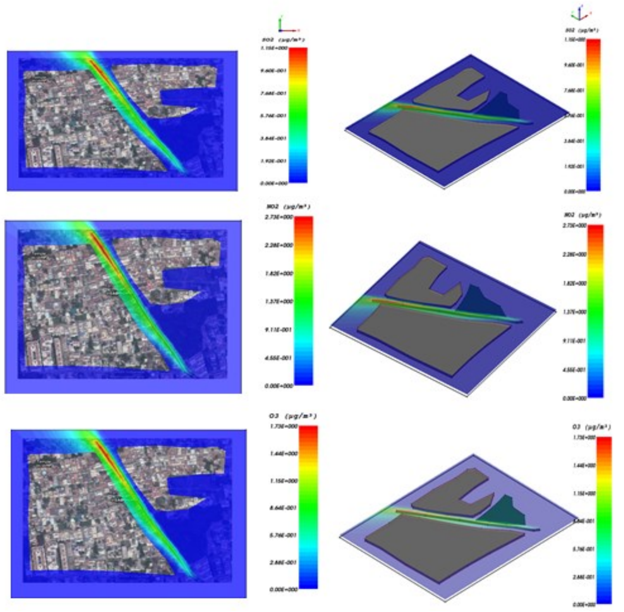


Figure 11. Represents 2D and 3D Views of pollutant dispersion in an Industrial zone

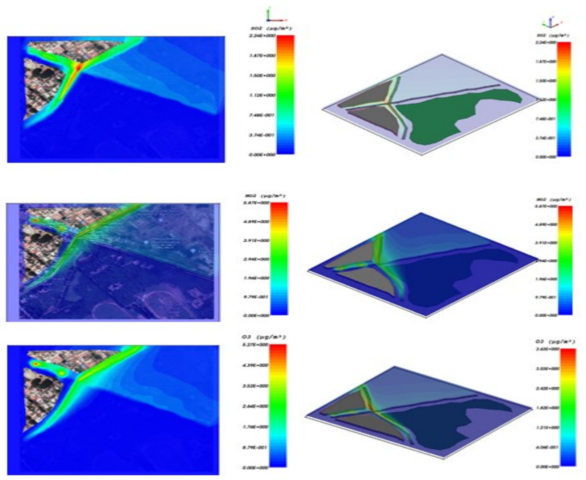


Figure 12. Represents the 2D and 3D views of pollutant dispersion in a commercial zone

4. Conclusion

The present study has attempted to assess ambient air pollution and seasonal variation by measuring and analyzing the ambient air pollutant concentration and dispersion pattern during the year 2021. This research investigates ambient air pollutant monitoring and modeling in selected four locations (Ganapathy - residential zone, Gandhipuram - commercial zone, Singanallur - traffic zone, and Sundarapuram - Industrial zone) in Coimbatore from January to December 2021. The variation of pollutant concentrations (seasonal difference) of the major five pollutants and the category of AQI in selected locations are identified. The maximum concentration of PM_{10} and SO_2 was observed in the industrial zone; the maximum concentration of $PM_{2.5}$, NO_2, and O_3 was observed in the commercial zone, followed by the traffic zone. Specifically, Particulate matter less than 2.5 microns was found higher in all zones in Coimbatore, followed by PM_{10}. Identification of sources is very important, and it is required to do the spatial and seasonal pattern analysis for air quality parameters. In all four zones, variations of pollutants were recorded, and the reason for variation was also analyzed. The current air quality index in Coimbatore has been analyzed accurately by this study. The local meteorological conditions have strongly influenced the profile of ambient air pollutants; Pearson correlation coefficients were measured to analyze the interconnection among different pollutants in the selected sites. characterization of air pollutants at various zones can be identified easily by continuous monitoring of ambient air quality and several atmospheric variables.

This research uses Fluidyn-PANACHE modeling software to identify the pollutant dispersion and flow pattern under various meteorological parameters. The Fluid Panache dispersion results also agree with the experimental analysis carried out in this study. If the rate of pollution present in that specific location increases means the dispersion range of pollutants also gradually increases with respect to the nature of the environment. The terrain features and stability of atmospheric conditions both pointedly disturb gaseous pollutants flow and dispersion pattern in all the selected sites. Regarding seasonality aspects, source areas and seasonal changes in transport pathways have been observed; However, all the selected locations were generally affected during the winter due to anthropogenic activities and long-range transport of pollutants. CFD model Fluidyn-Panache can be very useful in planning strategies for air quality management at the local and regional levels and can provide a rational basis for air pollution control. Fluidyn panache plays a significant part in any air quality management system if accurately planned and assessed.

Declaration

Ethics approval: Not applicable

Author Contributions

All authors contributed to the experimental analysis, and study conception. Material preparation, analysis of data, and content writing were performed by S. Sadheesh. Draft preparation, corrections, and validation of test results were performed by J. Jeyanthi. The two authors read and approved the final manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Aswini A.R, Hegde P, Prabha R. Nair S., and Aryasree. (2019). Seasonal changes in carbonaceous aerosols over a tropical coastal location in response to meteorological processes, *The science of the Total Environment*. **656**:1261–1279 https://doi.org/10.1016/j.scitotenv.2018.11.366

Athira V, Geetha P, Vijayakumar R, and Soman K.P. (2018). DeepAirNet: Applying Recurrent Networks for Air Quality Prediction. *International Conference on Computational Intelligence and Data Science, Procedia Computer Science*, **132**, 1394–1403.

Bhakiyaraja S., Vaithyanathan S., Palanivelraja S., and Prasad V.K. (2016). Dispersion of Air Pollutant In the neighborhood of a typical thermal power station under critical wind speed using Cfd-Fluidyn Panache, *International Journal of Mechanical Engineering and Technology*, **7**(6), November–December 245–252.

Bodor Z, Bodor K, Keresztesi A., and Szep R. (2020) Major air pollutants seasonal variation analysis and long-range transport of PM10 in an urban environment with specific climate conditions in Transylvania (Romania), *Environmental Science and Pollution Research* **27**:38181–38199 https://doi.org/10.1007/s11356-020-09838-2

Borrego C.M. Coutinho A.M. Costa, *et al*. (2014). Challenges for a New Air Quality Directive: The role of monitoring and modeling techniques, Urban Climate. http://dx.doi.org/10.1016/j.uclim.2014.06.007

Casazza M, Lega M, Jannelli E, Minutillo M, Jaffe D, Severino V, Ulgiati S. (2019). 3D monitoring and modeling of air quality for sustainable urban port planning: Review and perspectives, *Journal of Cleaner Production*, **231**, 1342–1352, ISSN 0959–6526, https://doi.org/10.1016/j.jclepro.2019.05.257.

Chauhan A., and Pawar M. (2010). Assessment of Ambient Air Quality Status in Urbanization and Commercial Centers of Uttarkhand (India), *New York Science Journal*, **3**(7).

Coimbatore city census. (2011). Data. http://www.census2011.co.in/census/city/492-coimbatore.html.

Coimbatore Current weather report (2021) https://www.Worldweatheronline.com

CPCB. (2011). Guidelines for measuring Ambient *Air Pollution Monitoring*, **1**, Delhi.

Dey S, Girolamo D.L, Donkelaar V.A *et al*., (2012). Variability of outdoor fine particulate (PM2.5) concentration in the Indian Subcontinent: A remote sensing approach, *Remote Sensing of Environment* **127**:153–161, http://dx.doi.org/10.1016/j.rse.2012.08.021

Freitas M.C, Pacheco A.M.G, Verburg T.G, and Wolterbeek H.T. (2010). Effect of particulate matter, atmospheric gases, temperature, and humidity on respiratory and circulatory diseases' trends in Lisbon, Portugal, *Environmental Monitoring and Assessment*. **162,** 113–121 DOI:10.1007/s10661-009-0780-5

Ganguly T, Kurinji L., Selvaraj, Sarath K. Guttikunda. (2020). National Clean Air Programme (NCAP) for Indian cities: Review and outlook of clean air action plans, *Atmospheric Environment,* X, **8**, 100096, ISSN 2590–1621, https://doi.org/10.1016/j.aeaoa.2020.100096.

Garg N., and Gupta C. (2020). The Great Smog Month and Spatial and Monthly Variation in Air Quality in Ambient Air in Delhi, *India Journal Health Pollution,* **27**: 200910

Gaur S.N., Tripathi V.P., Tare V.k, and Shukla S.P. (2014). Four-year measurements of trace gases (SO2, NOx, CO, and O3) at an urban location, Kanpur, in Northern India, *Journal of Atmospheric Chemistry,* **71** 283–301 DOI: 10.1007/s10874-014-9295-8

Goyal P, Gulia S, Goyal S.K. (2021). Identification of air pollution hotspots in urban areas - An innovative approach using monitored concentrations data, *Science of The Total Environment*, **798**, 149143, ISSN 0048–9697, https://doi.org/10.1016/j.scitotenv.2021.149143.

Grivas G, Chaloulakou A, *et al*. (2004). Temporal and spatial variation of PM10 mass concentration within greater Athens, Greece. *Water air soil pollution*, **158**: 357–371, https://doi.org/10.1023/B:WATE.0000044859.84066.09

Gulia S, Shukla N, Padhi L, Bosu P, Goyal S.K., Rakesh Kumar. (2022). Evolution of air pollution management policies and related research in India, *Environmental Challenges*, **6**,100431, ISSN 2667–0100, https://doi.org/10.1016/j.envc.2021.100431.

Guo D, Zhao P, Wang R, Yao R, and Hu J. (2020). Numerical simulations of the flow field and pollutant dispersion in an idealized urban area under different atmospheric stability conditions, *process Safety and Environmental Protection* **136** (310–323), https://doi.org/10.1016/j.psep.2020.01.031

Guo H, Wang Y, and Zhang H. (2017). Characterization of criteria air pollutants in Beijing during 2014–2015, *Environmental Research* **154** (334–344) http://dx.doi.org/10.1016/j.envres.2017.01.029

He j, Gong S, Yu Y, Yu L, *et al*. (2017). Air pollution characteristics and their relation to meteorological conditions during 2014e2015 in major Chinese cities, *Environmental Pollution*, 1–13, http://dx.doi.org/10.1016/j.envpol.2017.01.050

Huang X., Gao L, Guo D, and Yao R. (2021). Impacts of a high-rise building on urban airflows and pollutant dispersion under different temperature stratifications: Numerical investigations, *Atmospheric Pollution Research* **12** (100–112) https://doi.org/10.1016/j.apr.2021.02.001

Kortoçi P, Motlagh H.N, Zaidan A.M, Fung L.P, *et al*. (2022). Air pollution exposure monitoring using portable low-cost air quality sensors, *Smart Health*, **23**, 100241, ISSN 2352–6483, https://doi.org/10.1016/j.smhl.2021.100241

Li R, Dong Y, Zhu Z, Li C, and Yang H. (2019). A dynamic evaluation framework for ambient air pollution monitoring, *Applied Mathematical Modelling* **65** (52–71) https://doi.org/10.1016/j.apm.2018.07.052

Manju A., Kalaiselvi K. Dhananjayan V, *et al*. (2018). Spatio-seasonal variation in ambient air pollutants and influence of meteorological factors in Coimbatore, Southern India. *Air Quality, Atmosphere & Health* https://doi.org/10.1007/s11869-018-0617

Meenakshi and Elangovan (2000). Assessment of Ambient *Air Quality Monitoring and Modelling in Coimbatore City*

Meenakshi and Saseetharan. (2003). Analysis of Seasonal Variation of Suspended Particulate matter and Oxides of Nitrogen with References to Wind Direction in Coimbatore City, IE (1) *Journal, EN*, **84**

PANCHE F. (2010). User Manual. FLUIDYN France/TRANSOFT *International*, **7** Edition.

Perillo H.A, Broderick B.M, Gill L.W, *et al*. (2022). Spatiotemporal representativeness of air pollution monitoring in Dublin, Ireland. *Science of the Total Environment* **827**–154299, http://dx.doi.org/10.1016/j.scitotenv.2022.154299

Sadheesh S., and Kumar M. (2019). Ambient air quality monitoring and modeling in Coimbatore city, *Indian journal of Environmental protection IJEP,* **39** (6), 524–530

Sarath K. Guttikunda, Rahul Goel, Pallavi Pant, (2014). Nature of air pollution, emission sources, and management in the Indian cities, *Atmospheric Environment*, **95**, 501-510, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2014.07.006

Saravanakumar R.S., Sivalingam S. Elangovan. (2016). Assessment of Air Quality Index of Coimbatore City in Tamil Nadu. *Indian Journal of Science and Technology*, **9**(41), DOI: 10.17485/ijst/2016/v9i41/99185,

Sofia D, Giuliano A, Gioiella F, Barletta D, and Poletto M. (2018). Modeling of an air quality monitoring network with high space-time resolution, *Computer-Aided Chemical Engineering, Elsevie*r, **43**, 193–198, ISSN 1570–7946, ISBN 978044464356, https://doi.org/10.1016/B978-0-444-64235-6.50035-8

Talib M.A., and Jasim N.M, (2021). GIS-GPS-based national air pollution monitoring system, *Materials Today: Proceedings*, ISSN 2214–7853, https://doi.org/10.1016/j.matpr.2021.05.445

Tominaga Y, Stathopoulos T. (2011). CFD modeling of pollution dispersion in a street canyon: Comparison between LES and RANS, *Journal of Wind Engineering and Industrial Aerodynamics,* **99** (340–348)

Waersted G.E, Sundvor I, Denby R.B, andMu Q. (2022) Quantification of the temperature dependence of NOx emissions from road traffic in Norway using air quality modeling and monitoring data, *Atmospheric Environment*: **13**, 100160, ISSN 2590–1621, https://doi.org/10.1016/j.aeaoa.2022.100160

Wang C, Zhao L, Sun W, Xue J, and Xie Y. (2018). Identifying redundant monitoring stations in an air quality monitoring network, *Atmospheric Environment* **190** (256–268) https://doi.org/10.1016/j.atmosenv.2018.07.040

Wang Y, Ying Q, Hu J, Zhang H. (2014). Spatial and temporal variations of six criteria air pollutants in **31** provincial capital cities in China during, 2013–2014, *Environment International*, **73** (413–422) http://dx.doi.org/10.1016/j.envint.2014.08.016

Zhan Y, Luo Y, Deng X, Grieneisen ML, Zhang M, Di B. (2018). Spatiotemporal prediction of daily ambient ozone levels across China using the random forest for human exposure assessment. *Environmental Pollution*. **233**:464–473

Zhang Q, Wu S, Wang X, Sun B, and Liu H. (2020). A PM2.5 concentration prediction model based on multi-task deep learning for intensive air quality monitoring stations, *Journal of Cleaner Production*, **275**, 122722, ISSN 0959–6526, https://doi.org/10.1016/j.jclepro.2020.122722.