Development of model for measuring direction and transportation of urban air emission

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Abstract

This research has designed a unique method of simulating the movement of air pollutants with respect to winds direction in urban areas. A good study of variable and invariable parameters for the factors of air emissions in urban area has assisted in conceptualization of major forces and factors that are responsible for the dispersion of air pollution in urban areas. These parameters have been used in the design, development and simulation of this model. New findings include, establishment of method for tracing the direction of air emissions in urban areas using trigonometric and vector analysis. The model was designed on the basis of variable and invariable parameters for the factors influencing air pollution in urban areas. Good choice of constraints was made. The Model has quantitatively established the mathematical and physical relationship between the air concentration and deposition values of one or more pollution species in space and time. It uses atmospheric, and meteorological variables and parameters, to describe removal and transformation processes in urban areas. The fundamental approach and empirical analysis of various factors governing the distribution of the air pollutants in urban areas gave new results and findings. Results are discussed.

1 Introduction

Urban Air pollution varies with industrial pollution on the basis of the emission properties, type and sources. Air pollutants differ in mass and density, which facilitate dispersion and transportation. Also the movement of vehicles and activities in urban areas influence the direction and transportation of urban air pollution. The first step in modeling of air pollutants direction and dispersion in
urban areas include good study of atmospheric constituents and factors affecting air pollution in urban areas. The research has established a good method of tracing the movement of pollutants in urban areas with respect to wind fields. It has a unique system of finding the wind fields and appropriate vector component directions of air pollution in urban areas. This model has been designed and developed on the basis of variable and invariable parameters for the factors influencing air pollution in urban areas. Good choice of constraints was made. This model design for Air Pollutant dispersion and transportation in urban areas, involved establishment of mathematical and physical relationship between the air concentration and deposition values of one or more pollution species in space and time. It uses variables and invariable parameters of atmospheric, and meteorological factors, to describe removal and transformation processes. Model is a representation of reality, which provides an understanding of the underlying process of pollutant emission and dispersion. We have to note that when environmental authorities are mapping out areas for establishment of industries, which are the major sources of air pollution, careful predictions will be necessary, for the direction of the pollutants and to know where concentrations are likely to occur. These predictions are often made in the form of modeling. The prediction of the model, helps the environmental planners to know how safe or how destructive such establishment can be to the people of the area of concentration. How is model formulated? This is a matter of research and better understanding of atmospheric process in which model engineers look into a logical use of the model. In other to formulate, develop or improve a model an inventory of requirements regarding time and space resolution has to be taken. The best solution to model design is pure assumptions in the model. With this in mind plus a clear knowledge of the output requirements this model is formulated. The air pollutants transportation and their directions were put into consideration in formulating this model. Transport is distinguished from dispersion in modeling on spatial and temporal basis. The diurnal average wind velocity data has been used in this model to determine Transport with the horizontal and vertical motion components of the air pollutants in urban areas. Air pollutant dispersion refers to the expanded or increased volume of the air emission parcel caused by wind turbulence over temporal and spatial scales smaller than the averaging time or space interval. The differences in Models depend on how they simulate the movement of pollutants with winds, how they generate wind field, and how they choose suitable transport layer. Some models are equipped with their own wind field generation or interpolation schemes. Such models designed to use wind fields derived from other models with simple modifications as input to their computations. Others simply use the ready-made wind field without modification.

2 Background Studies

Most models differ in their choice of a transport layer to suit their purpose. Some models use mixed-layer trajectories; others use winds averaged in a 0.1- to 10-km layer George and Hidy[1]. In some cases one model may chose to use a
constant barometric pressure height (850 or 925 mb) isoharic trajectory. While others use adjusted surface geostrophic winds. The choice of transport layers can drastically change the path of a trajectory when strong wind shears are present, Michael and Raynor[2]; Michael and Hales[3]. Eliassen[4] compares surface geostrophic trajectories and isoharic 850-mb trajectories for transport distances out to 1000 km. The mean distance between the two trajectories for 179 simulations was 246km and the median distance was 140 km. Thus, the determination of a true trajectory involves considerable uncertainty. A large part of this uncertainty also arises from the limited amount of meteorological information available for trajectory models and the length of the trajectory time step. The ATAD model uses tipper-air data that are typically available at a spatial resolution of approximately 400 km and a temporal resolution of 12 hours George M Hidy[1]. The MS model supplements the tipper-air observations with hourly surface data at a spatial resolution of approximately 100 km. The trajectory time steps for the ATAD and MS models are 3 hours and 1 hour respectively. The transport layers in the two models are determined by different methods. Clark and Cohn[5] carried out model evaluation Study across North America with tracer experiment. It has been found that, on the average, the linear distance from the source to the trajectory end point for the ATAD model was 62% greater than that for the MS model George M Hidy[1]. This difference was attributed to the bias of the ATAD model toward the upper-level winds. They also found a consistent directional discrepancy between the trajectories. The largest differences were found when the wind direction was changing rapidly because of the passage of a storm system through the area of interest. The ability of a model to estimate accurately the deposition distribution of pollutants depends critically on the accuracy of the estimated transport wind fields. These wind fields must be available at the spatial and temporal resolution of the transport models, and they must be physically realistic. Clayton and Davis[6] described the way of tracing air pollutants by marking. An accurate specification of the wind field is even more critical for flow over complex terrain. Significant meso-scale variations in large-scale flow patterns can be induced by the heterogeneity of the terrain, such as lifting and channeling of flow near obstacles, and the variations caused by differential heating or cooling of the earth’s surface. The linear models do not account for the diurnal and latitudinal variability in photochemical activity and are suitable only for long-term predictions. However, a diurnal variation for short-term applications is incorporated by specifying different daytime and night time oxidation rates Kleinman [7]. Specified diurnal and seasonal cycles are also used in some linear Lagrangian models. Aalast and Bergsma[8] described removal and transformation processes in the atmosphere with respect to SO2, Nox. Chang, Binkowski and Seaman[9] gave analysis of regional acid deposition model and engineering model. Crawford and Todd[10] showed the usefulness in computer program for calculating the atmospheric dispersion of large clouds. Deardorf and Willis [11] have described the method for parameterization of diffusion into the mixed layer.
3 Methodology

3.1 Model Structures

This research has developed a model, which incorporates essential components for analysis of environmental and meteorological factors influencing air pollutants dispersion in urban areas. It has a component for determination of direction of air pollutants using trigonometric and vector analysis to determine urban air pollutant velocity, speed and direction. Donald[12] showed the relationship between velocity, acceleration and speed. Observation data of surface wind was favored in the aspect of Wind-field in validation of this model. The urban wind speed diurnal average data of August 1997 in Kajang town of Malaysia and urban wind direction diurnal average data of the same August 1997 in Kajang town of Malaysia are used in the model validation and predictions. The diurnal average data were very useful to the accuracy of the model prediction. Wind speed data and wind direction data are required to estimate the particle speed and direction. In order to consider the turbulent motion effect, diurnal averages are used in this model, to take into account, the eddies. Turbulence is the small-scale irregular flow superimposed on the mean motion. Turbulence is characterized by irregular swirls of motion called eddies. Diurnal is actually, brought about by irregular flow as well. Turbulent motion in the atmosphere is made up of spectrum of eddy sizes.

3.2 Directional Tracing

This research has considered the Galileo's formula of object motion on a line. The formula is given by $D=kt^2$. Where $D$ is the distance that the air pollutant falls (starting from the air pollutant source and neglecting air resistance) in time $t$. And $k$ is a constant depending on the units of measurement. Velocity $V(t_1)$ of the object at $t_1$ is given by

$$V(t_1) = x'(t_1) = \lim_{t_2 \rightarrow > t_1} \frac{x(t_2) - x(t_1)}{t_2 - t_1}$$

Take position vector $r = (x, y)$ of the point $P$ as shown in fig 1 below:

![Figure 1: The position vector.](image)
Taking that the pollutant is at a point P in the \((x_i, y_j)\) plane with coordinates \(x_i\) and \(y_j\) the magnitude of the position vector \(r = (x, y)\) is written as \(|r|\) and

\[ |r| = \sqrt{x^2 + y^2} \]  

(2)

The direction of \(r\) is the unique angle \(\theta \in [0, 2\pi)\) for which is also the direction of the pollutants.

### 3.2.1 Position of air pollutant particle in the two dimensional plane.

The velocity of the air pollutant in the two dimensional plane is also given by:

\[ v = \frac{dr}{dt} = \frac{dx}{dt} \hat{i} + \frac{dy}{dt} \hat{j} \]  

(4)

The speed of the air pollutant in two dimensional plane is therefore, reduced to:

\[ ||v|| = \frac{dD}{dt} = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} \]  

(5)

While the acceleration of the pollutant particle in two-dimensional plane give:

\[ a = \frac{dv}{dt} = \frac{d^2r}{dt^2} = \frac{d^2x}{dt^2} \hat{i} + \frac{d^2y}{dt^2} \hat{j} \]  

(6)

Let us consider the force acting on the motion of the air pollutants using Newton’s second law of motion:

\[ F = ma \]  

(7)

This research has summed up the meteorological and atmospheric forces in urban areas acting on the motion of air pollutants along their trajectories to be equal to \(F\). Where \(m\) is the mass of the urban air pollutant particle and “\(a\)” is the acceleration of the urban air pollutant particle along it’s trajectory.
4 Simulation and Validation

Bird [13] showed resolution of vector. Many facts about air pollution propagation in urban areas have been seen. Air Pollutant particles are physical quantities being governed by numerical values and direction in space and time. The transport trajectories of the pollutant particles in urban areas have been traced and at each point are diagrammatically represented. The figure 2 below shows the position of air particle at the point P. The horizontal displacement is along the x axis. The magnitude of resultant force OP is the speed of the pollutant particle.

![Figure 2: Resolved forces on particle on motion](image)

The vertical and horizontal components due to the forces acting on the pollutant particle have been diagrammatically represented. The horizontal component of the flow force of the pollutant particle in urban areas is given by:

\[ H = P_{S1}\cos\theta + P_{S2}\cos\phi \quad (8) \]

Where the \( P_{S1} \) is the mean of the diurnal average of the wind-speed. While \( P_{S2} \) is the diurnal average of the wind-speed. The angle \( \theta \) is the angle of the mean for the diurnal average of the wind. While \( \phi \) is the angle of diurnal average of the wind.

The vertical component of the flow force of the pollutant particle is given by:

\[ V = P_{S1}\sin\theta + P_{S2}\sin\phi \quad (9) \]

The magnitude of the resultant speed of the pollutant particle is given by:

\[ R_s = \sqrt{H^2 + V^2} \quad (10) \]
This resultant speed is the actual speed of the air pollutant at the position P in a given time \( t \). The direction of the pollutant particle is given by:

\[
\Phi = \arctan \left( \frac{V}{H} \right)
\]

(11)

The distance of the pollutant particle after \( t \)-time is given by:

\[
D_p = txR_s
\]

(12)

![Correlation between Wind Direction Data and Predicted Air Pollutant direction](image)

Figure 3: Correlation between Kajang Air Direction and Predicted Air Direction

The above Figure 3 shows the correlation between the wind direction in Kajang and predicted air pollutants direction. The movement of the air pollutants is well correlated with the wind direction in Kajang as well.
Figure 4: Wind Direction of Kajang vs Predicted pollutant direction

Figure 4 above shows the line-chart of wind direction of August 1997 in Kajang, town of Malaysia compared with the predicted movement of the pollutant particle. The movement of the pollutants, which is also, the direction of the air particle perfectly aligned with each other.

Figure 5: Chart for Kajang Wind direction vs Predicted pollutant direction

Figure 5 above shows the column-chart of the wind direction of August 1997 in Kajang, town of Malaysia with the predicted pollutants direction. The wind direction data of Kajang is in agreement with the predicted pollutants direction.
5 Conclusion

This research has maintained that Urban Air pollution varies with industrial pollution on grounds of the emission properties, type and sources. Air pollutants have different mass and density, which determine their dispersion and transportation. Also the movement of vehicles and activities in urban areas influence the dispersion and transportation of urban air pollution. Consequently, movement of urban air pollution is different from industrial. But all air pollutants whether in urban area or industrial move along the wind direction. This model for measuring urban air emission direction and transportation has been seen to be effective on the grounds of its' prediction capacity during validation. There is perfect prediction of urban air pollutants direction, which corresponds with wind direction of Kajang urban. The Urban wind direction data of Kajang is well correlated with the predictions of urban pollutants direction by the model. This shows that urban air pollutants move along the direction of the air just like in industrial. The result of this research has confirmed that wind constitute force to air emissions.

References


