COMPUTER SIMULATION FOR DISPERSION OF AIR POLLUTION RELEASED FROM A LINE SOURCE ACCORDING TO GAUSSIAN MODEL

Emad A.A., Sayed M. El Shazly, and Kassem Kh.O.

South Valley University, Faculty of Science at Qena, Department of Physics.
Laboratory of Environmental Physics
Email: ealy21@yahoo.com

A line source model, developed in laboratory of environmental physics, faculty of science at Qena, Egypt is proposed to describe the downwind dispersion of pollutants near roadways, at different cities in Egypt. The model is based on the Gaussian plume methodology and is used to predict air pollutants' concentrations near roadways. In this direction, simple software has been presented in this paper, developed by authors, adopted completely Graphical User Interface (GUI) technique for operating in various windows-based microcomputers. The software interface and code have been designed by Microsoft Visual basic 6.0 based on the Gaussian diffusion equation. This software is developed to predict concentrations of gaseous pollutants (eg. CO, SO_2, NO_2 and particulates) at a user specified receptor grid.

Keywords: U*rban area, Air pollution, Dispersion model, Line source, Vehicles emission*.

1. INTRODUCTION

Smoke being emitted to air is a common source, among others, of air pollution. The rising process of smoke depends on atmospheric ambient, meteorological conditions, emission parameters, such as the action of atmospheric stratification, initial emission momentum and temperature, wind direction and speed as well as turbulent behaviors, and so on [1]. Environmentalists are greatly interesting into the smoke dilution process and scope, because pollutant dispersion in air may seriously affect regional air quality, and has been widely concerned by human society.

In recent years, in most of the countries, the air pollution caused by the vehicular exhaust emissions (VEEs) has been a substantial increased due to addition of more and more vehicles on roadways yearly to meet increase in transportation demand [2, 3, 4].

Line source emission modelling is an important tool in screening of VEEs and helps in control and management of these emissions in urban environment. The US Environmental Protection Agency (EPA) and many other research institutes have developed a number of line source models (LSMs), either deterministic or statistical, to describe temporal and spatial distribution of VEEs on roadways. A review of LSMs based on deterministic, numerical, statistical and artificial neural network has been presented by [2].

One of the dominant sources of air pollution affecting environmental living quality in urban areas is road traffic-induced air pollution [5, 6, 7]. Providing information about traffic air pollution and finding out its distribution is therefore a crucial starting point for planning effective measures to improve air quality. Such information helps decision makers to optimize e.g. urban design.

A line source model, developed in laboratory of environmental physics, faculty of science at Qena, Egypt is proposed to describe the downwind dispersion of pollutants near roadways, at different cities in Egypt. The model is based on the Gaussian plume methodology and is used to predict air pollutants' concentrations near roadways.

1.1 The Objective of the Present Study

Studies carried out by Ministry of State for Environmental Affairs indicated that vehicles' emission contribute with 26% from total pollution loads with suspended particulate matter in Greater Cairo, more than 90% of total pollution loads with carbon monoxide, 90% of total pollution loads with hydrocarbons and 50% of total pollution loads with nitrogen oxides. These gases had harmful impacts on both environment and public health [8].

Vehicles number were multiplied from 1993 to 2008, licensed vehicles were about 4.3 million during 2008 compared to 4.1 million vehicles during 2007, and 2.1million during 1993. Private vehicles represent 48% (2 million) from the total number of licensed vehicles followed by trucks about 19% (0.82 million), then motorcycles about 17% (0.72 million), and taxies about 8% (0.32 million).

During 2008, 63% from the total private vehicles were centralized in urban governorates, followed by Upper Egypt with about 21% from the total private vehicles, while border governorates did not exceed 1%. [8]

In view of the above facts, this paper concerns with studying the pollutants emitted from different vehicles roaming the streets. In this direction, simple software has been presented in this paper, developed by authors, adopted completely Graphical User Interface (GUI) technique for operating in various windows-based microcomputers. The software interface and code have been designed by Microsoft Visual basic 6.0 based on the Gaussian diffusion equation. This software is developed to predict concentrations of gaseous pollutants (eg. CO, SO_2, NO_2 and particulates) at a user specified receptor grid.

2. METHODOLOGY

2.1 Theoretical Software Approaches

The software is a Gaussian type computer–based line source model, developed to predict concentration of gaseous pollutants CO, SO2, NO2 and particulates on various types of roads, speeds of different vehicles and different modes of driving at traffic intersections. Source inventory of this software has been designed according to traffic data, available in urban cities of Egypt.

The common Gaussian line source model is based on the superposition principle, namely concentration at a receptor, which is the sum of concentrations from all the infinitesimal point sources making up a line source [9]. Figure (1) shows the details of line source and wind coordinate systems. Let the length of the roadway be 'L', which makes an angle 'θ' with the wind vector. The middle point of the line source can be assumed as 'origin' for both coordinate systems, having same Z-axis.

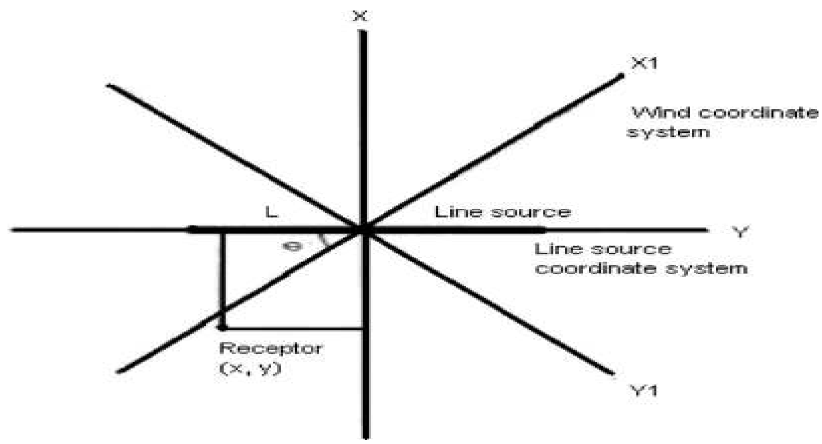

Fig. (1). Orientation of line source and wind direction coordinate system, source [9].

The present software does not include chemical reactions. The model is based on the Gaussian diffusion equation and is so formulated so that it can be applied for any wind direction and any length of the line source. The principle involved in the development of the model is that the road is divided into a series of elements, from which incremental concentrations are then computed and summed up. The mixing height in this model is assumed to be infinite. The equation used by this software to calculate pollutant concentration at these receptors as given by Luhar and Patil [10] is follows:

$$C(x,y,z) = \frac{Q}{2\sqrt{2\pi}\,\sigma_z\,(u\sin\theta + u_o)} \left\{ e^{\frac{-1}{2}\left(\frac{z-H}{\sigma_z}\right)^2} + e^{\frac{-1}{2}\left(\frac{z+H}{\sigma_z}\right)^2} \right\}$$
$$\times \left[erf\left(\left| \frac{\sin\theta\,(L/2 - y) - x\cos\theta}{\sqrt{2}\sigma_y} \right| \right) + erf\left(\left| \frac{\sin\theta\,(L/2 + y) + x\cos\theta}{\sqrt{2}\sigma_y} \right| \right) \right] \quad (1)$$

where, C is the concentration of the pollutant at any receptor (g/m3), Q is the source emission rate per unit length (g/sec), x, y and z are the receptor coordinates relative to the centre of the line source (x is the downwind, y is the crosswind distance and z is the height), θ is the angle between the wind direction and the road, varying between 0-180 degrees, H is the effective source height, L is the line source length, u is the average wind speed, u_o is the wind speed correction due to traffic wake and has different values for different stability classes [11], erf is the error function and σ_y *and* σ_z are the horizontal and vertical dispersion coefficients, respectively and are functions of distance x and atmospheric stability class [12]. A simplified schematic of the model is shown in Figure (2).

2.2 Estimation of Emission Rate (Q)

The emission rate (Q) of air pollutants on a reasonably straight highway from a continuous line source per unit length can be determined as the product of the emission factor (E) and traffic density (V) [13, 14].

$$Q = \sum_{i} E_i \times V_i \qquad (2)$$

The traffic density can be calculated by the following equation:

$$V_i = N_i v_i \qquad (3)$$

where, N number of vehicle and v is speed.

Emission factor of vehicle type (i) is given by Table (1).

Table 1. Emission factors in grams of pollutant per vehicle km, source [13]

Type of vehicle	Emission factors (g per vehicle km)		
	SO_2	SPM	NO_x
Motor cycles (LTV)	0.02	0.20	0.07
Petrol-driven cars (MTV)	0.08	0.33	3.20
Diesel-driven cars (MTV)	0.39	2.00	0.99
Heavy duty vehicles (HTV)	1.5	3.00	21.00
Average values*	0.19	0.55	2.89

* composition LTV, 65% ; MTV, 25%; HTV, 10%

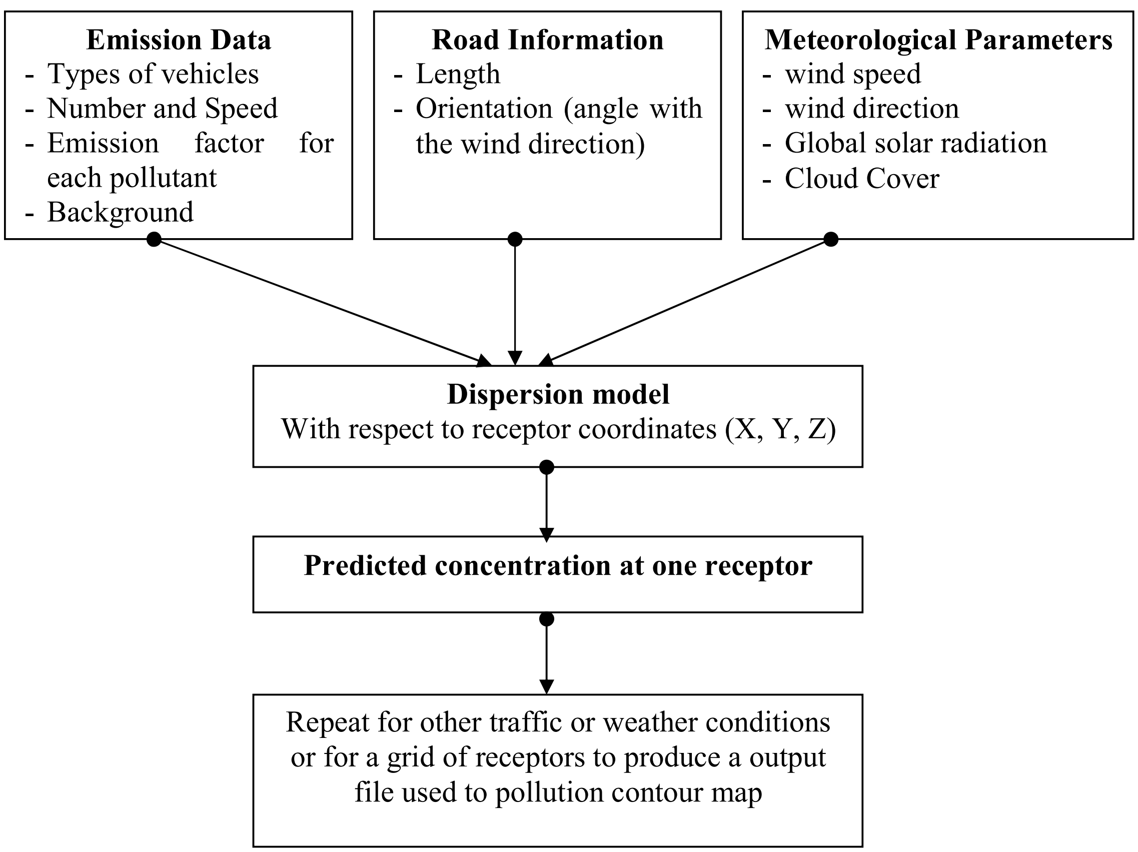

Fig. 2. A simplified schematic of the model.

While emission factor for pollutant CO given by used Stanford Research Institute CO model [15] which gives the relation between speed (m/s), v and emission factor (kg/m/veh), E as shown in equation (4):

$$E = \alpha v^{\beta} \tag{4}$$

where α *and* β are the dimensionless constants [16].

2.3 Input Data Requirement

- Meteorological data**:** Wind speed (m/s), Wind direction (0^0 – 360^0), stability class (A-F) [or global solar radiation (W/m2), cloud cover (>50% or <50%) and time for calculate (daytime or night time)].
- Emission source data: Type of the vehicle, average speed of the vehicle (km/h) and number of vehicle for each type. Type of pollutant (CO, NO_2, SO_2 and PM) and emission Factor for each pollutant. Length and orientation of the line source.
- Receptors' data: Coordinates for receptors which user determined. Also user can enter distance for each coordinate and the software will generate numbers of receptors with step entered by user for each distance.

3. NUMERICAL RESULTS AND DISCUSSIONS

The required presentation of pollutant levels predicted by the model may vary at different locations. Where there is a particularly sensitive area, such as housing or a public building very near to a proposed road development, it may be desirable to study the likely impact of the traffic at that site under a range of conditions. Other proposed routes, particularly in urban districts, may be so located that their impact on the whole of the surrounding area is important. It has been made possible, therefore, to suit the model output to a variety of circumstances through giving an output file. Four methods are available, which are:

1. Prediction at a single receptor for varying meteorological conditions.
2. Prediction at a single receptor for varying traffic flows.
3. Prediction at a single receptor for varying meteorological conditions and traffic flows.
4. Prediction at a grid of receptor for one set of meteorological conditions and traffic flows.

For the first three methods the results are given numerically. This is also true for method 4 but, additionally, the results are produced in the form of input to a program which will generate isopleths of pollutant concentration for the area covered by the receptor grid to produce a pollution map. In the following will present some example of output numerical results from the software.

Figure (3) show concentration profile across a line source, Calculated for unit emission rate and wind speed and wind direction normal to the source. In the both side of the road, the concentration decrease with increase distance.

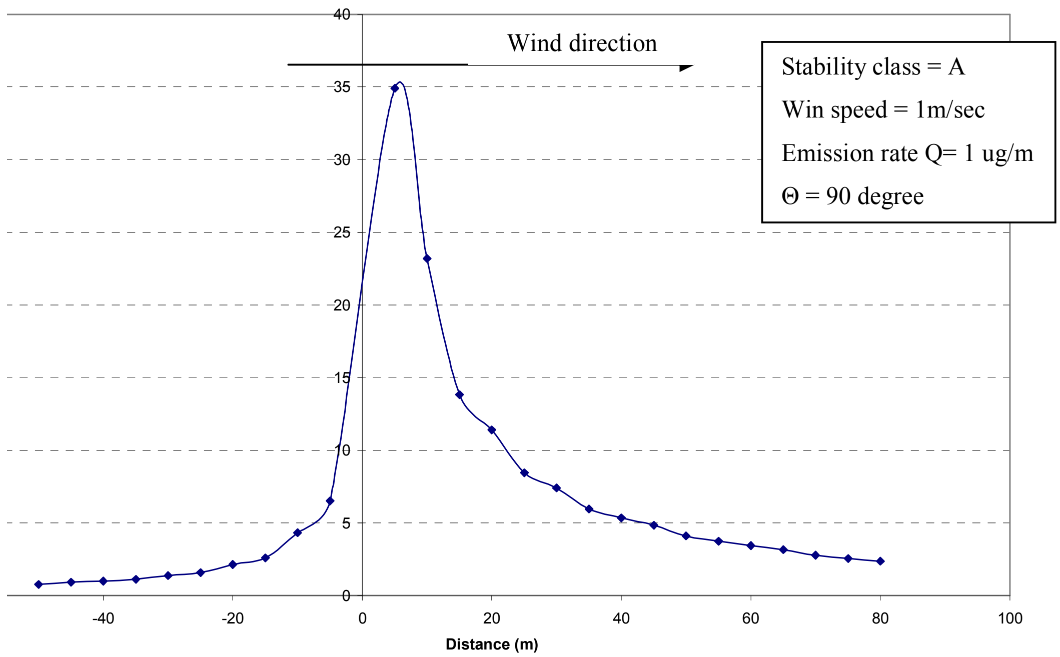

Fig (3). Concentration profile across a line

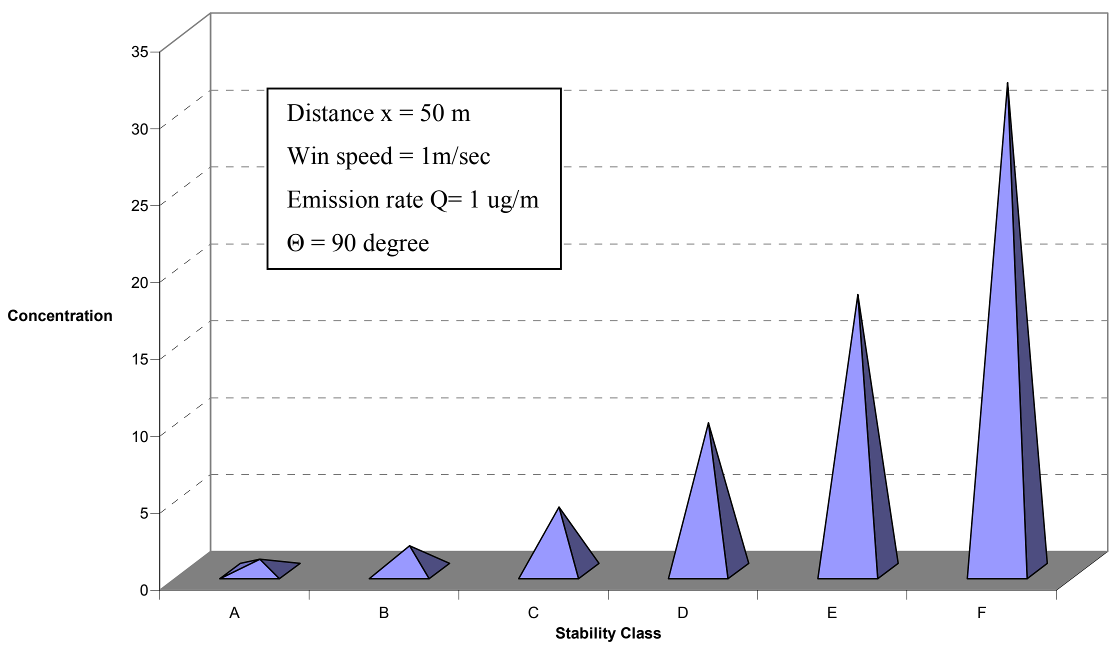

Fig (4). Concentration with stability classes

Figure (4) show the relation between concentration and stability (A very unstable atmosphere and F very stable Atmosphere), which indicate that stability play a major role in the dispersion of air pollutants.

Figure (5) show the relation between concentration and θ which the angle between the wind direction and the road. this diagram indicate that when the road parallel to the wind direction means a decrease in the spread of pollutants near the road.

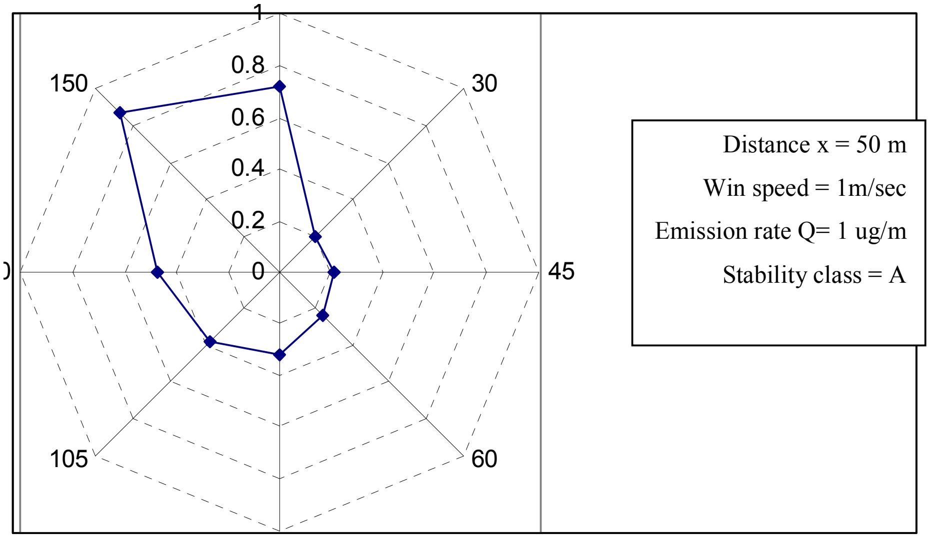

Fig (5). Concentration with the orientation of the road

5. CONCLUSION AND FUTURE DEVELOPMENT

Simple software is developed to predict concentrations of gaseous pollutants (eg. CO, SO_2, NO_2 and particulates) released from a line source according to Gaussian model at a user specified receptor grid. This software has been shown to be useful tool to studying the dispersion of pollutants emitted from different vehicles. This is the first step for air quality management of air pollutants in Egypt. However, the continued study of the emission and dispersion of motor vehicles exhaust would enable some of the shortcoming of the present software to be investigated, such as emission rate, vehicles behavior, topography and background contributions.

6. REFERENCES

[1] Liren Yu and Paulo Ignacio, *American journal of applied science* **2 (2)**, 533-538(2005).

[2] Nagendra, S. M. S. and Mukesh Khare, *Atmospheric environment* **36**, 2083-2098(2002).

[3] Sharma, P. and Khare, M., Transportation Research D 6, 179-198(2001).

[4] Mayer, H., *Atmospheric environment* **33,** 4029-1037(1999).

[5] Duclaux, O. et al, *Atmospheric environment* 36(2), 5081-5095(2002).

[6] European Environment Agency, *Europe's environment: the third assessment. Environmental Assessment* **Report 10**, Copenhagen, Denmark, (2003).

[7] Rebolj, D. and Sturm, P.J., *Environmental Modelling and Software* **14(6)**, 531-539(1999).

[8] EEAA, *Egypt State of Environment* **Report 2008**, (2009).

[9] Nagendra, S. M. S. and Mukesh Khare, artificial Neural Networks in Vehicular Pollution Modelling, Springer, appendix A, 163-173, (2007).

[10] Ashok K. Luhar and R. S. Patil, *Atmospheric environment* vol. 23 No. 3, pp. 555-562(1989).

[11] David P. Chock, *Atmospheric environment* vol. 12, pp. 823-829(1978).
[12] D. O. Martin, *J. Air Pollution Control Assoc.* **Vol 24**, p 832(1976).
[13] Goyal, P. , Rama Krishna, T. V. B. P. S., "A Line source model for Delhi",India (1999).
[14] Missed reference.
[15] Johnson, W. B., et al,, *J. Air Pollution Control Assoc.* **Vol 23,** No 6, 490-498(1973).
[16] Sathitkunarat, S. and B. Satayopas, Effect of Tr (2003)