Assessing the impact of a Bio-terrorist Attack using Mathematical Model

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Summary

In recent years there has been greater stress on conflict prevention all over the world. A key role in this effort has been played by science and technology. However, the challenges of international relations and national security are growing more complex. Hence, special measures would be needed for dealing with security issues. In this regard, mathematical model can prove to be a benefit. One such model known as Gaussian plume model, where airborne release of bio-agent anthrax can be explained with mathematical method, is discussed here.

I. Introduction

Bioterrorism is terrorism by intentional release of biological agents like bacteria, viruses, or toxins. In last few decades various pathogenic organisms have been identified as possible weapons in bio-terrorist attack. These agents have seldom been dispersed in aerosol form where tiny particles of liquid or solid are released in air. One such example where airborne release of bio-agent results from inhaling an aerosol of anthrax spores into the respiratory tract is invariably fatal. Anthrax, caused by the bacterium Bacillus anthracis, is found in nature and can be easily cultured, which makes it a relatively easy agent for terrorist to acquire and prepare. In 2001, envelopes containing anthrax spores were mailed to various government and media leaders in United States, causing some causalities and immense panic in the country. In 1982, there were 24 cases of oral-pharyngeal anthrax in a rural northern Thailand outbreak following the consumption of contaminated buffalo meat.[1] Also in 1979, a city of 1.2 million in Russia was attacked, where 79 persons were reported to have developed inhalation anthrax, and 68 of these died[2].

As is evident from the foregoing paragraph, an intentional release of bio agent in form of aerosol could prove disastrous to human health. To counter the deadly effects of the anthrax pathogen, various mathematical and probabilistic techniques like Markov chain model[3], Bayesian approach[4], Plume model[5], have been proposed in the development of life saving measures. These models enable us to predict how the outbreaks will evolve and to quantify the effectiveness of public health responses. One such study concluded that there was no significant threat to personnel in areas contaminated by 1 million spores per square meter either from traffic on asphalt-paved roads or from a runway used by helicopters or jet aircraft[6]. A separate study showed that in areas of ground contaminated with 20 million Bacillus spores per square meter, a soldier exercising actively for a 3-hour period would inhale between 1000 and 15,000 spores [7].

It is to be noted that the above mentioned models have been developed based on parameters best suited for western countries. However in Indian context, weather conditions differ drastically as Indian topography and terrain features are greatly influenced by the prevailing climatic conditions.

This paper describes the basic Gaussian plume model, which can help to predict distribution of anthrax particles depending on weather conditions. Hence it is an attempt to envisage the anthrax outbreak in Indian scenario.

II. Gaussian Plume Model

Gaussian plume model (GPM) is a mathematical technique, which is commonly used to describe dispersion of air pollutants in the atmosphere as shown in Fig. 1. The technical literature on atmospheric dispersion modeling is quite wide and dates back to the early 1930s. Sir Graham Sutton derived one of the early air pollutant plume dispersion equation in 1932.

The GPM describes dispersal over distance up to 10 km from a source. It predicts concentration of gases or particles downwind from a point source. Spore concentration at a given point depend on the distance from the source, the wind direction, the number of released spores, the wind speed and the amount of mixing in the atmosphere as affected by weather conditions. The spore concentration C at location (x, y ,z) downwind from a source is calculated as [8]:

$$C = \underbrace{\frac{Q}{2\pi u}}_{1} \cdot \underbrace{\frac{\exp(-y^2/2\sigma_y^2)}{\sigma_y}}_{2} \cdot \frac{1}{\sigma_z}\left\{\underbrace{\exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right]}_{3a} + \underbrace{\exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]}_{3b}\right\} \quad (1)$$

where:

1. C(x,y,z) is the concentration of the emission (kg/m3).

2. Q is the quantity or mass of the emission (kg/s).

3. u is the wind speed (m/s) .

4. H is the height of the source above ground level (m).

In this algorithm, we are concerned with dispersion in all three dimensions (x, y, and z):

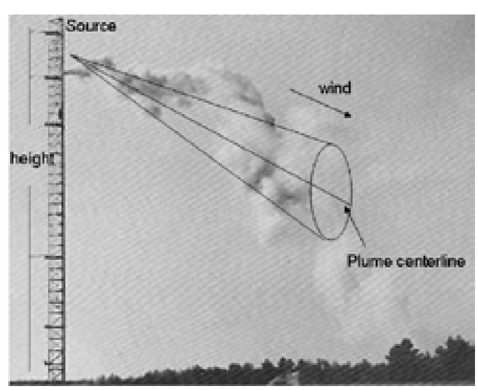
- longitudinally (in the x direction), also called the plume axis, lies in the direction of the mean wind.

- laterally (in the y direction) in the crosswind direction.

- vertically (in the z direction) which is the height above the surface.

The number of released spores and the wind speed are described in factor 1 of Eq. (1). Factors 2 and 3 describe the height and width of the plume. Factor 2 describes the crosswind shape of the plume as a Gaussian curve with standard deviation with its peak on the x-axis. The factors 3a and 3b describe the shape of the plume in the vertical direction. Factor 3a describes a Gaussian curve with standard deviation and a peak at height H. The standard deviations and determine the height and width of the plume. For a given x, the maximum concentration is at the plume centerline and decreases exponentially away from the centerline at a rate dependent upon the sigma values, and .

Now, if we assume anthrax spores are released from certain height over a large city, the concentration of the release can be estimated from Eq. 1, if the wind patterns are known. Based on that the most effected geographical area can be located and hence medical response strategies can be estimated.



Source: Slade et al. Meteorology and Atomic Energy, 1968.

Fig. 1 Gaussian plume concentration.

III. Conclusion

As is evident from the above, Gaussian plume model can be used to gauge the impact of a bio-terrorist attack. This method is effective in the determination of spread of aerosolized biological weapon like anthrax.

In terms of security threats it is imperative that government authorities must be prepared to face such bio-terrorist attack. The most crucial task is to be ready with effective models so that correct location of dispersion of such attacks can be estimated and hence causalities can be minimized. Hence from a policy viewpoint, these models focus on addressing a key issue of decision-making and can be a tool for a broader political agenda.

The scope of these methods can be extended to calculate the effect on population density which could give more realistic assessment.

Endnotes:

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