Mathematical Modeling for the Design of Greenbelts for Air Pollution Control: An Engineering Perspective

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Abstract--- *If trees and smaller plants are viewed as if they are pollution control devices in the hands of environmental engineers, they can be perceived as biopumps, particulate traps, reactive absorbers of pollutants, and cooling towers.*

But whereas the usual engineering devices do not make a pretty sight and can't launch a thousand poems, trees and other vegetation can. Nor can the usual pollution control devices attract birds and other colourful fauna as trees do.

From the environmental engineer's perspective, the species of trees and shrubs can be scientifically chosen and planted in a pattern around a source of air pollutant, and in a manner so as to effectively reduce the pollution caused by that source. The entire system can be optimized to ensure maximum pollutant removal of target pollutants at minimum utilization of land and other costs.

In this paper the work of this group on the design of greenbelts based on mathematical modeling has been summarized in the context of the global stat-of-the-art.

Keywords--- *Greenbelts, Mathematical Modeling, Optimization, Design, Pollution Control*

I. INTRODUCTION

THE fact that if strips of trees and other forms of vegetation are planted around sources of air pollution, such 'greenbelts' tend to attenuate the pollution, has been known since the mid 19th century [1].

Extensive research has also been done on the pollution attenuation capability of different tree species [2-5]. But, in comparison, much less is known on how to maximize gains from a greenbelt. The normal proactive is to put a circular ring of trees around a pollution source. But it is easy to see that such an approach is likely to have limited utility, if at all. This is because dispersion of particulates and gaseous pollutants never occurs radially in a uniform manner from the epicenter of the exiting plume. Rather, the dispersion is non-

uniform and is strongly dependent on wind-speed, wind-direction, atmospheric stability, and other meteorological factors.

When polluted air comes out of a chimney or a tall stack, it does not evenly mix with the ambient air in all directions. Rather, and based on the meteorological conditions prevailing at that instant, the polluted air plume acquires complex shapes and travels in a difficult-to-predict manner. Such a plume may not come close to the ground to meet the greenbelt but may do so several hundred meters away from the greenbelt. It may also remain close to the ground for varying distances before getting diluted beyond harmful levels. If a greenbelt has to serve its purpose of pollution control effectively, the greenbelt must be located at places where the pollutant plume is likely to come close to the ground. These locations would change from season to season as the meteorology – especially the predominant wind directions and velocities – also change from season to season.

Hence, even as forecasting plume behavior is a complex task, unless it is done effectively the greenbelt would not be located where it is most needed. Further intricacies, necessitating sophisticated R & D, are encountered in deciding which species of trees and other vegetation are to be included in a greenbelt because this decision is influenced by the agroclimatic conditions of the area; not all trees can be grown everywhere. Even more sophistication is needed to decide the optimal height of the trees and the patterns in which trees of different species, and other vegetation, is to be planted in a greenbelt to maximize attenuation.

II. THE MAIN OBJECTIVES OF GREENBELT DESIGN

Even though air pollution control may be the primary motivation to raise greenbelts (GB), a multiplicity of objectives can be fulfilled by GB development. A greenbelt can ranging from the micro-level air pollution abatement to enhancement of socio-economic values of the region. serve as a cushion against accidental fires, explosions, and toxic releases [6]. The additional benefits of GB are protection of soil from erosion, improving the micrometeorology of the area, and beautification of the landscape. Yet another major benefit can be generation of employment and fostering a sense of participation in lay people towards environmental protection.

III. FACTORS INFLUENCING THE DESIGN OF GREENBELT

Green belt development mainly depends upon the following:

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1. Climatic factors;
2. Nature and extent of pollution load;
3. Assimilative capacity of the ecosystem; and
4. Soil and water quality.

For optimum design of greenbelt, the following key variables must be considered:

1. Height and canopy of trees,
2. Mean wind velocity and direction,
3. Distance from source or occurrence of maximum ground level concentration,
4. Pollutant concentration,
5. Nature of pollutants,
6. Dry deposition velocity of plants (specific to pollutants and plants), and
7. Topography and size of the land available.

IV. THE WORK OF THE PRESENT GROUP IN THE CONTEXT OF THE STATE-OF-THE-ART

Attempts to model the process of greenbelt design have been few and far between. After the initial efforts of [7, 8], which had focused on suspended particulate matter, significant advancements were made by [9-13]. These authors have developed a body of knowledge considering the atmospheric dispersion of pollutants and the manner of their interception in the greenbelt.[14] have simulated the impact of greenbelts, separated by 10, 20, and 30 m intervals, on five major air pollutants (SO_x , NO_x , NH_3 , SPM, and respirable PM) to record a 'micro-canyon effect' in the first two types of greenbelt intervals. But no new model was developed by [14].

Figure 1: The Process of Greenbelt Design

Figure 2: Steps Involved in Characterizing Atmospheric Stability

Figure 3: Steps Involved in Estimation of Dispersion Characteristics

Figure 4: Algorithm for the Design of Greenbelt

Figure 5: Typical Geometry of a Rationally Designed Greenbelt

The present authors have built upon the previous work and advanced it in the following terms [15-18].

- a. whereas in the previous treatments the dispersion of pollutant plume has been treated as a first order concentration decay phenomena, we have incorporated much more rigorous treatments of pollutant dispersion,

- b. as these are central to the decisions on where to locate the greenbelts and how broad the greenbelts should be; we have also incorporated effects of atmospheric stability on plume shapes as these factors, too, are very important in deciding upon the geometry and the location of the greenbelts;
- c. we have included separate treatments for greenbelts to

be located in coastal areas and deeper inland, as meteorological factors influencing dispersion in the two areas are significantly different;

- d. separate treatments have been given for dispersion and control of 'heavy gases'; and for as-dense-as-air and lighter-than-air gases.

The overall process of greenbelt design as developed by us is summarized in Figure. 1. In order to design an effective greenbelt the atmospheric stability of the region must be determined first followed by estimation of the concentration profile and the geometry of the plume. The input from this exercise can then be used to determine the most appropriate location for the greenbelt. The first two parts of the process have to be accomplished as elaborated in Figures 2 and 3. The design algorithm is presented in Figure 4. Details of the model-building, validation, and some of the applications have been extensively reported [1, 15-19].

The methodology has been applied to greenbelt development for several industries and industrial complexes. An illustrative example, pertaining to the Sedarapet industrial estate, Puducherry, is presented in Figure 5.

V. CONCLUSION

In this article we have presented a mathematical model to assist in the design of greenbelts. The application of the model [1, 15-19] demonstrates its validity. The study also underscores the fact that without determining the correct geometry of the greenbelt on the basis of pollutant dispersion-attenuation modeling, it is not possible to derive much benefit from a greenbelt.

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