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Utilizing multiobjective analysis to determine an air quality monitoring network in an industrial district

Jehng-Jung Kao*, Ming-Ru Hsieh

Institute of Environmental Engineering, National Chiao Tong University, Hsinchu, Taiwan 300, ROC

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Abstract

An industrial district with polluting factories operating inside poses a potential threat to the air quality in the surrounding areas. Therefore, establishing a proper air quality monitoring network (AQMN) is essential for assessing the effectiveness of imposed pollution controls, strategies, and facilities in reducing pollutants. The geographic layout of such an AQMN should assure the quality of the monitored data. Monitoring stations located at inappropriate sites will likely affect data validity. In this study, a multiobjective approach was explored for configuring an AQMN for an industrial district. A dispersion model was employed to simulate hourly distribution of pollutant concentrations in the study area. Models optimizing pollution detection, dosage, coverage, and population protection were established. Alternative AQMNs with varied station numbers and spatial distributions were obtained using the models. The resulting AQMNs were compared and evaluated for effectiveness in monitoring the temporal and spatial variation of pollutants. Discussion of the differences among the AQMNs is provided. This multiobjective analysis is expected to facilitate a decision-making process for determining an appropriate AQMN.
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1. Introduction

Air pollutants emitted from factories located in industrial districts are potentially hazardous to surrounding environments, affecting human health, materials, agriculture, forestry, etc. Establishing a proper air-quality monitoring network (AQMN) to evaluate the spatial and temporal distribution of pollutants and the effectiveness of pollution control strategies at industrial facilities is critical to ensure the health of the residents and environment in the area surrounding an industrial district.

The effectiveness of an AQMN depends primarily on the suitability of monitoring sites. Unsuitable sites cannot effectively reflect the characteristics of pollution. In the early days, monitoring site planning was done based on empirical judgment or simple qualitative rules, such as distance of polluters to neighboring residential areas and population density. Systematic approaches were developed in the 1970s. For instance, Nakamori et al. (1979) designed a monitoring network to obtain the best

*Corresponding author. Tel.: +886 3 5731869; fax: +886 3 5731759.
E-mail address: jjkao@mail.nctu.edu.tw (J.-J. Kao).

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estimation of overall mean pollutant concentrations. Graves et al. (1981) adopted detection and protection capabilities as the major objectives in designing an AQMN. Noll et al. (1977) applied statistical analyses in developing a planning method for an AQMN by targeting large point pollution sources, while detecting violations of air-quality standards was used as the primary objective. Noll and Mitsutomi (1983) further proposed a dosage index in designing an AQMN. Most studies have considered only a single objective. Such designs may be flawed. For example, if detecting violations of air-quality standards is used as the primary objective, monitoring stations would likely be located the leeward of the prevailing wind direction, and, thereby, be unable to determine the spatial and temporal variations of airborne pollutants. Although increasing the number of monitoring sites enlarges coverage area, cost also increases. Therefore, properly locating monitoring sites using a multiobjective model for AQMN planning is potentially a superior approach.

In a previous multiobjective study, Modak (1985) planned an AQMN for Taipei City, Taiwan, based on the objectives of maximum coverage and maximum violation detection for monitoring single and multiple pollutants. Trujillo-Ventura and Ellis (1991) proposed a model using the objectives of spatial coverage, violation detection, and data validity, and a weighting method was applied to find the most suitable network. Arbeloa et al. (1993) established a multiobjective planning method for AQMNs based on a hypothetical case and attempted to find the optimal solution based on a utility function. Although these studies considered multiple objectives, their models are not directly applicable for planning an AQMN for an industrial district. For example, if detection of maximum average concentration is the primary objective, then monitoring sites would likely be over-concentrated, located around the high average concentration spots. Other objectives, such as maximizing population coverage, should also be considered when resident safety is a concern. The multiobjective mixed-integer programming model proposed in this study utilizes four objectives: maximum detection capability of pollution potential, maximum dosage detection capability, maximum detection area, and maximum population protection.

Given that wind speed and directions vary over time, these uncertainties should be taken into account. Therefore, this study used the ISCST3 (USEPA, 1995) model to simulate pollutant distributions of under hourly wind fields for a whole year in order to assess the uncertainty in pollutant distribution affected by wind speed and direction. Based on the results obtained from the simulation model and multiobjective models established, this study compared the effects of various objectives on selection of monitoring sites in a case study, with the intention to devise a suitable monitoring network and to demonstrate the applicability of the established model.

2. Multiobjective model development

Potential zone, detection coverage areas, and meteorological uncertainty are first explained. Description of the applied models, with objective formulations and relevant constraints, then follows.

2.1. Potential zone

A monitoring site is generally located where it can best measure the pollution distributions. Given that pollutants spread throughout the atmosphere, surface pollutant levels between a location and a pollution source have a distribution relationship as depicted in Fig. 1 which shows different potentials of pollution for the areas surrounding a pollution source. Noll et al. (1977), who pointed out that a monitoring station should be located in a potential zone, defined such a zone as having pollutant concentrations larger than 90% of the maximum. However, the maximum concentration of a plume can be excessively high, and by taking 90% of the maximum to define a potential zone may exclude some other potential areas. Therefore, as shown in Fig. 1, this study demarcated detection areas based on concentrations greater than 100 ppb, the domestic standard limit for daily average concentration of SO_x.

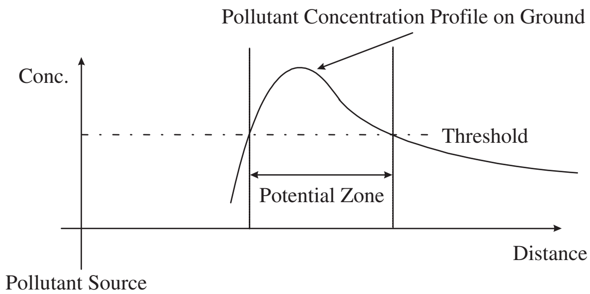

Fig. 1. Potential zone.

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