Journal of Hazardous Materials 271 (2014) 98–107

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Assessing vanadium and arsenic exposure of people living near a petrochemical complex with two-stage dispersion models

Chia-Pin Chio [a], Tzu-Hsuen Yuan [a], Ruei-Hao Shie [a,b], Chang-Chuan Chan [a,*]

[a] Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Taipei, Taiwan
[b] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan

HIGHLIGHTS

- Two-stage dispersion models can estimate exposures to hazardous air pollutants.
- Spatial distribution of V levels is derived for sources without known emission rates.
- A distance-to-source gradient is found for V levels from a petrochemical complex.
- Two-stage dispersion is useful for modeling air pollution in resource-limited areas.

ARTICLE INFO

Article history:
Received 25 October 2013
Received in revised form 5 February 2014
Accepted 6 February 2014
Available online 15 February 2014

Keywords:
Industrial source complex (ISC)
Pollution
Naphtha cracking
Petrochemicals processing
Vanadium
Arsenic

ABSTRACT

The goal of this study is to demonstrate that it is possible to construct a two-stage dispersion model empirically for the purpose of estimating air pollution levels in the vicinity of petrochemical plants. We studied oil refineries and coal-fired power plants in the No. 6 Naphtha Cracking Complex, an area of 2,603-ha situated on the central west coast of Taiwan. The pollutants targeted were vanadium (V) from oil refineries and arsenic (As) from coal-fired power plants. We applied a backward fitting method to determine emission rates of V and As, with 192 PM_{10} filters originally collected between 2009 and 2012. Our first-stage model estimated emission rates of V and As (median and 95% confidence intervals at 0.0202 (0.0040–0.1063) and 0.1368 (0.0398–0.4782) g/s, respectively. In our second stage model, the predicted zone-average concentrations showed a strong correlation with V, but a poor correlation with As. Our findings show that two-stage dispersion models are relatively precise for estimating V levels at residents' addresses near the petrochemical complex, but they did not work as well for As levels. In conclusion, our model-based approach can be widely used for modeling exposure to air pollution from industrial areas in countries with limited resources.

1. Introduction

Toxic air pollutants can generally be divided into four groups: gaseous pollutants, persistent organic pollutants, particulate matter, and heavy metals [1]. Such air pollutants simultaneously produce adverse effects on human respiratory, cardiovascular, nervous, urinary, and digestive systems. Mostofsky et al. [2] modeled the association between health outcomes and multiple constituents in $PM_{2.5}$ (particles with aerodynamic diameter less than 2.5 μm), concluding that black carbon (BC), nickel (Ni) and vanadium (V)—all residues of fuel oil combustion—are associated with a higher stroke risk in Boston. In epidemiological studies, airborne inorganic arsenic (As), which is mainly released from coal-fired power plants [3,4], has been associated with several cancers [5,6]. Cyrys et al. [7], Moreno et al. [8,9] and de la Campa et al. [10] showed high concentrations of metals, such as Ni and V, in fine particles emitted from petroleum refinery complexes in Germany and Spain. Moreno et al. [4] documented coal combustion as the source of As in Madrid, Spain, especially in the winter season. Watson et al. [3] proved that V and Ni are emitted not only from oil-fired combustion but also from coal-fired processing. In Pakistan, Khan et al. [11] showed that V species can translocate from soil near a thermal power plant into vegetables and grasses.

Kampa and Castanas [1] furthermore demonstrated that heavy metals in ambient air, such as V and As, generate free radicals

* Corresponding author at: College of Public Health, National Taiwan University, Global Health Center, Rm. 722, No.17, Xu-Zhou Rd., Taipei 100, Taiwan.
Tel.: +886 2 33228082.
E-mail address: ccchan@ntu.edu.tw (C.-C. Chan).

http://dx.doi.org/10.1016/j.jhazmat.2014.02.008
0304-3894/

that oxidize lipids, proteins, and nuclear and mitochondrial DNA. Sørensen et al. [12] also concluded that V in ambient $PM_{2.5}$ produce reactive oxygen species (ROS) and cause oxidative DNA damage with subsequent adverse health effects, including cancer. In experiments with healthy human subjects exposed to air containing concentrated metal particles, both pulmonary neutrophil influx and blood fibrinogen increased, showing that these endpoints were linked to the soluble components in ambient fine particles [13]. Huang et al. [14] and Clancy et al. [15] used a gene expression approach which indicated that human lung cells exposed to V and As may promote the development of early stage cancers. Recently, The European Chemicals Agency (ECHA) [16] proposed a series of guidelines for assessing human health risk based on the registration, evaluation, authorization and restriction of chemicals (REACH) regulations. One important chapter concerns environmental distribution and fate and exposure estimation. The derivation of predicted environmental concentration (PEC) based on dispersion and deposition mechanisms in air compartments is robust.

The No. 6 naphtha cracking complex, located on the west coast of central Taiwan, has an overall area of 2603 ha and contains oil refineries and coal-fired power plants with an annual capacity of 25 million tons and 1.8 million kW of electricity generating power, respectively. The complex houses 64 plants and has 381 stacks [17–19]. Quantifying emission rates of hazardous air pollutants from each of these stacks by actual measurement is time-consuming, costly, and technically infeasible. Currently, the particle emission rates from these stacks are self-reported by the petrochemical companies using emission factors of US AP-42 [20]. However, the emission speciations for hazardous air pollutants used by the oil refinery and coal-fired power plants have not been evaluated yet in most developing countries. Traditionally, industrial source complex (ISC) models developed by the US Environmental Protection Agency (USEPA) [21] are used to

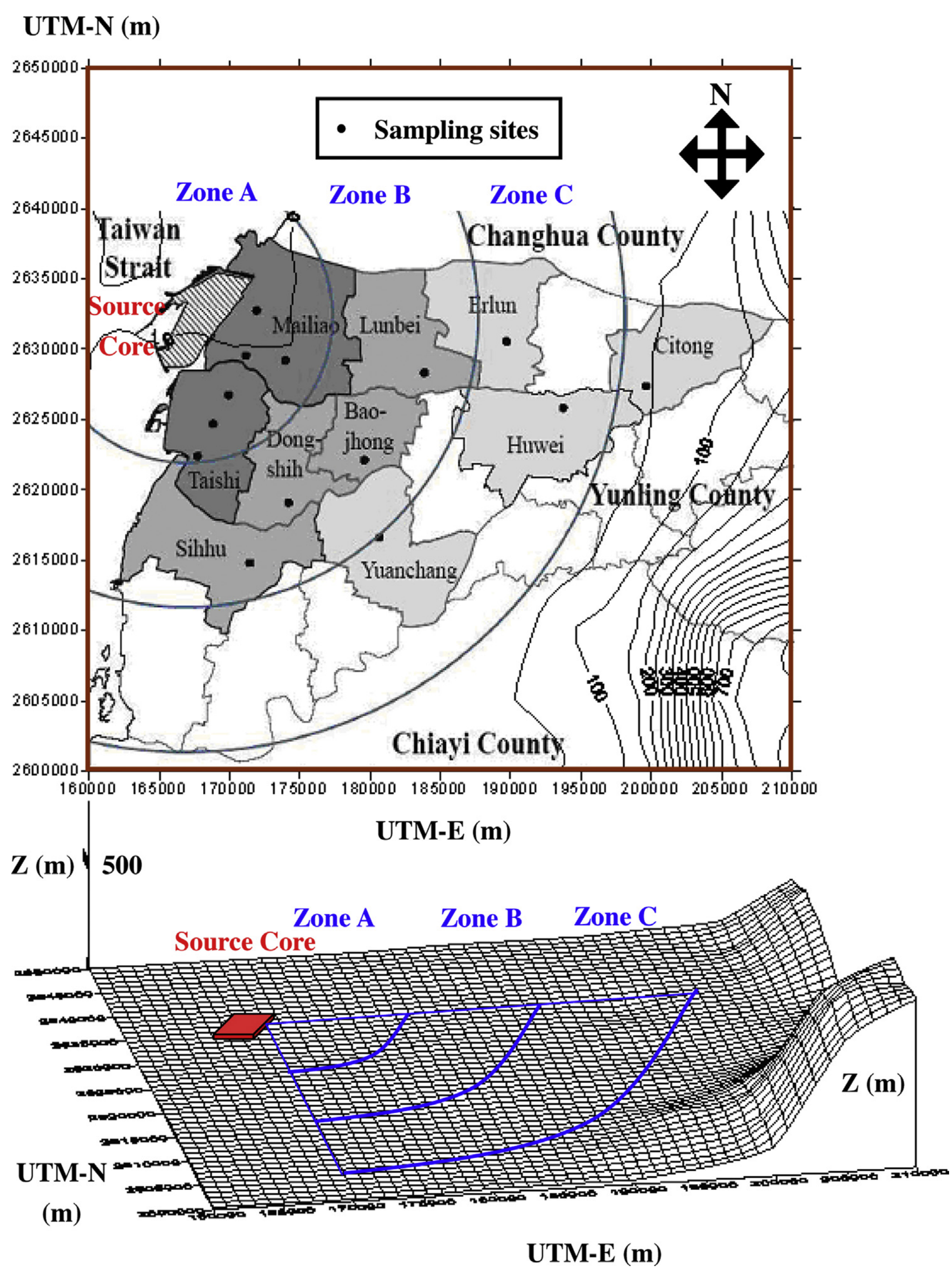

Fig. 1. Relative locations of districts, elevations, zones, source core, and sampling sites in the study area.