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Original Article

Evaluating Human Exposure to Emission from Incineration Plant Using AERMOD Dispersion Modeling

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Abstract

Background: The Air dispersion models are widely used to evaluate and predict the pollutants emissions from air pollution sources such as incinerators. This study attempts to predict the heavy metal pollutants dispersion emitted by an incineration plant impacting its surrounding area.

Methods: Several scenarios of emission rates coupled with the meteorological conditions were investigated using the AERMOD dispersion model.

Results: The maximum ground level concentration (GLC) of pollutants was within their respective air quality guidelines concentration and fall within the distance of 0.5 km from the stack.

Conclusion: The pollutant concentration decreases with distances from the incineration plant, which does not seem to contribute a significant human exposure problem to the residence living more than 1.5 km away.

Keywords: Pollution dispersion, AERMOD, Incinerator, Heavy metals

Introduction

There are different methods for the disposal of industrial wastes; incineration is one of the available options. Although this method of treatment reduces the volume of solid wastes significantly and possibly with thermal energy recovery, it is susceptible to emit toxic emissions (1). Among different emissions caused by incineration, heavy metals are of most concern in air pollution matters (2). The identification of heavy metals level emitted from incinerators has been investigated in several studies (3- 5). The high levels of exposure to heavy metals emissions such as Pb, Cd, As and Hg from this process are important due to their negative health and environmental effects (6, 7). The World Health Organization (WHO) International Agency for Research on Cancer has considered the carcinogenic effects of As, Cr and Cd (8, 9) and the neurotoxicity effects of lead and mercury. Thus, regulations imposed on industrial emissions are necessary in human and environmental health protection. Fortunately, air dispersion models are available to assess and evaluate the impact of these industrial sources into the surrounding environment. Studies have shown that air pollution dispersion models are accurate and suitable in forecasting pollutant dispersion and managing urban air quality (10, 11).

The application of different atmospheric dispersion models for example SCREEN, ISC and AERMOD in different situations has been addressed in the variety of literatures (12- 17). Patel and Kumar compared SCREEN and ISC dispersion models for mercury releases and concluded that ISC predicts emission dispersion better than SCREEN while SCREEN presents a more conservative result in considering the worst scenario (12).

The simulation of hydrogen cyanide concentrations have been analysed in the ambient air during gold extraction from ores by running ISCST3 and AERMOD dispersion models under rural and complex train options. The authors found that the predicted concentrations with ISCST3 exceed the measured concentration by an average factor of 2.4, while AERMOD predicted a lower value with an average factor of 0.76. Although the leach field is located in a rural area, the sensitivity assessment of the models based on both rural and urban options showed that the concentrations predicted were more precise with urban option. The results also showed that AERMOD model is more efficient in handling complex terrain compared to ISCST3 and setting the ISCST3 with urban option whereas reduces its shortcoming in complex terrain conditions (18). Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) behaviour emitting from a steel plant in northwest was investigated in Italy using AERMOD. The authors found that the predicted concentrations of pollutants from the steel plant were lower than the measured concentration in the monitoring station, indicating some other air pollution sources that contribute to the measured concentrations in the area (17). The aim of this study was to evaluate the impact of heavy metals emission for example Pb, As, Cd, and Hg from an incineration plant using the AERMOD dispersion model. The emission inputs were based on the actual and standard emission limits imposed for such a facility.

Materials and Methods

Location and Description of the Incineration Plant

An incineration plant is a solution to many developing countries for an incineration facility deals with industrial waste in the most environmentally friendly manner. The plant is designed and built on the principles of its ability to treat a wide variety of wastes, lower down time, operation and maintenance cost. The plant is equipped with a unit of fabric filter along with lime and activated carbon injection as the flue gas cleaning agent and a wet scrubber system. The plant is divided into four main sections including the feeding system, combustion, heat reduction and recovery unit and the air pollution control system as depicted in Fig. 1.

The Emission Concentration

Table 1 presents the emission concentration limits of selected pollutants imposed by the Department of Environment (DOE) on the plant, which was also used as the source input in the dispersion modelling exercise.

Table 1: Emission limits of metal concentration imposed on incineration plant

Pollutant	Limits, mg/Nm^3@corrected to 11% oxygen
As	0.5
Cd	0.2
Pb	1.4
Hg	0.2

Table 2 presents the average concentration, standard deviation and range of pollutant concentration emissions reported from the plant. Selected pollutants concentrations including As, Cd, Pb and Hg were considered in this study. On average, the concentration of As, Cd, Pb and Hg was 1%, 2%, 3% and 7% of their limits, respectively. The impact or contribution if any, of these metals pollutants onto the surrounding ambient air quality in the area was assessed and reported in this paper.

Atmospheric dispersion modeling

Air dispersion models are widely used in air pollution study to assess and evaluate the probable impact from industrial sources. AERMOD, promulgated by the U.S. EPA, was developed as a new air quality model in 1991 to replace the thus popular model, Industrial Source Complex (ISC) model.

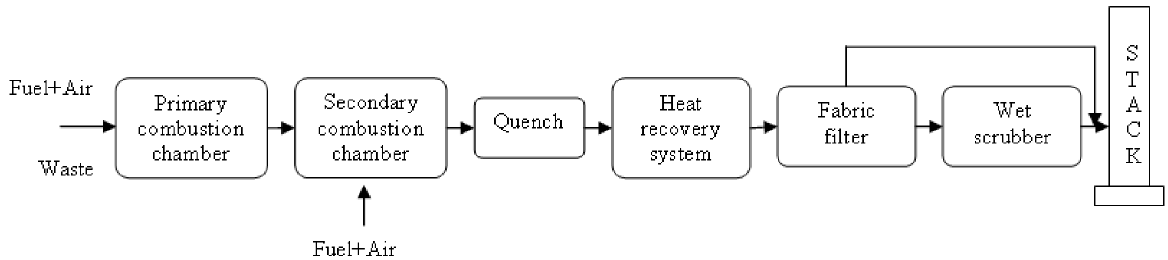

Fig. 1: The schematic process flow diagram of the incinerator plant

Table 2: Emission concentration of pollutant reported from the plant

Pollutants	Mean	Std Deviation	Min	Max
As	0.00392	0.00530	0.00138	0.00922
Cd	0.00391	0.00529	0.00138	0.00920
Pb	0.03667	0.00403	0.00361	0.07694
Hg	0.01368	0.01580	0.00212	0.02948

Note: Concentration is in mg/Nm^3 corrected to 11% O2.

The AMS/EPA Regulatory Model (AERMOD) is a collaborative between the U.S. Environmental Protection Agency (EPA) and the American Meteorological Society (AMS). AERMOD is a steady-state plume dispersion model, which assumes a constant of meteorological parameters over time (for example one hour). The model can assess the pollutant concentrations from a variety of sources and considers the dispersion of pollutants from stationary sources for a short-range (up to 50 km).

AERMOD is based on the assumption of a planetary boundary layer (PBL) which is the closest part of the atmosphere to the ground where ground friction exists. However, its thickness may vary between 100 m at night to 3 km during daytime. AERMOD uses the Gaussian probability density function in both the vertical and horizontal distribution in the stable condition and also in the horizontal distribution of convection condition, while the model assumes a bi-Gaussian probability density function in a vertical distribution.

The modeling system of AERMOD contains an air dispersion model processor, a meteorological data pre-processor called AERMET, and a terrain data pre-processor called AERMAP. The AERMET meteorological pre-processor program provides the meteorological data as the basic input data in AERMOD. AERMET presents two types of meteorological data files consisting of surface scalar parameters and vertical profiles of meteorological data. AERMAP facilitates the generation of hill heights scales for AERMOD (19).

In this study, the AERMOD model was initialized to predict the air quality surrounding the incineration plant. The source parameters used as input in AERMOD model were as the followings:

-Stack inside diameter: 1.3 m

-Release height or stack height: 60 m

- Gas exit temperature: 160ºC

-Gas exit velocity: 18 m/s

The meteorological variables such as atmosphere temperature, wind speed, wind direction, humidity rate and dew point temperature were obtained from the recorded data in KLIA meteorological monitoring station in 2010, which is the nearest station to incineration plant. The cloud cover, ceiling height and precipitation amount were available for the meteorological station for July 2010 and were imported to the AERMET pre-processor to estimate secondary meteorological parameters, such as the mechanical and convective mixing height. The terrain surrounding the plant is considered flat. Thus, it is expected that the concentrations are not affected by the region's topography characterized by a large flat area due to the gentle slopes and hence AERMAP was not applied for the modeling exercise.

Besides, AERMOD requires near-surface parameters for example surface Albedo, Bowen ratio and surface roughness length during the day selected for specific season and landuse surrounded the area, which was set to 0.16, 1.00, and 1.00, respectively.

Results

Table 3 presents the predicted maximum GLC of pollutants estimate for specified AERMOD averaging times for example 1h, 3h, 8h and 24h based on the actual emission rates, compared to the recommended ambient air quality guidelines established by the DOE or elsewhere in the world. The results demonstrate that the contribution from the plant was significantly low with respect to the recommended ambient limits. The 1h, 3h and 8h predicted GLC for Pb as an example is shown in Fig. 2, while its 24 h GLC is zero around the area. The predicted GLC of pollutants are likely to be higher in the north part of the plant across all averaging periods in accordance with the prevailing wind direction as presented in the wind rose of the KLIA station in Fig. 3.

Fig. 4 presents the isoplets of predicted 1h GLC of heavy metals for example Pb and Hg emission from the incineration plant, where they exhibit a similar dispersion patterns of pollutants with downwind distance. The 1h GLC of heavy metals for example As and Cd were predicted to be zero. The ground level concentration of different pollutants was predicted up to 8 km around the incinerator. The ground level concentration of pollutants was found to fall within the distance of 0.5 km from the stack while are significantly low further away from this distance.

However, to simulate the worst scenario, emission rates based on the limits imposed (as presented in Table 1) on the plant was used instead in the modeling exercise and the results are presented in Table 4 which showed that the predicted 1h maximum GLCs for all the pollutants were still significantly low compared to the ambient air quality guidelines.

Table 3: AERMOD predicted maximum GLC of heavy metals over averaging times of interest

Pollutant (ug/m^3)	1 h	3 h	8 h	24 h	Ambient air quality guidelines
Pb	0.00004	0.00002	0.00001	0	1.5
As	0	0	0	0	0.3
Cd	0	0	0	0	2
Hg	0.00001	0.00001	0	0	2

Table 4: Predicted pollutant maximum GLC based on emission limits imposed on incineration plant compared to the ambient air quality guidelines

Pollutant (ug/m^3)	1 h Maximum GLC based on limits imposed on plant	Ambient air quality guidelines
Pb	0.001 (0.1 %)	1.5
As	0.0019 (0.19 %)	0.3
Cd	0.00012 (0.012 %)	2
Hg	0.00012 (0.012 %)	2

(%) = percent of the ambient air quality guidelines

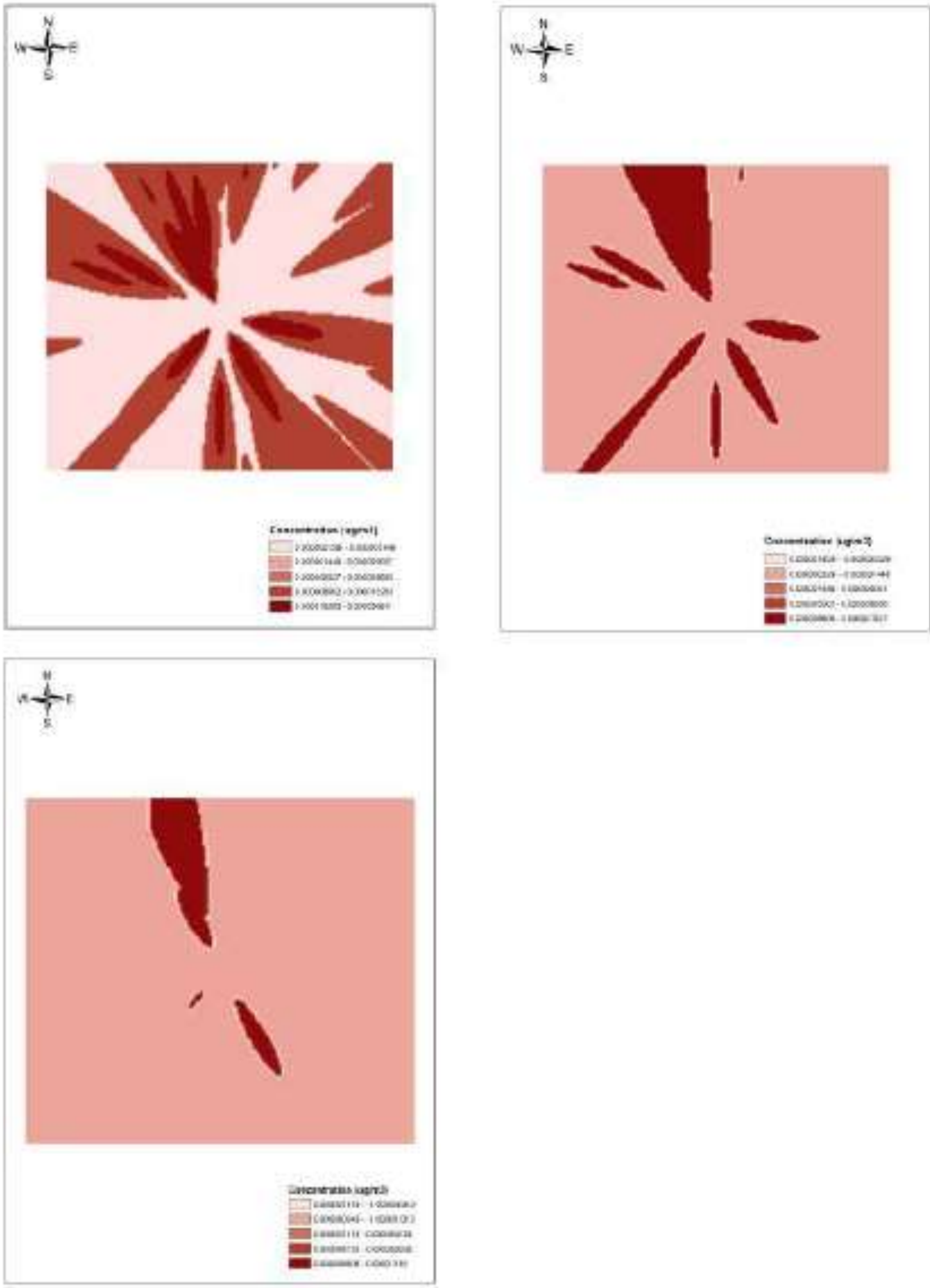

Fig. 2: The dispersion patterns of 1h, 3h and 8h GLC of Pb near the incinerator based on reported emission rates (from left to right)

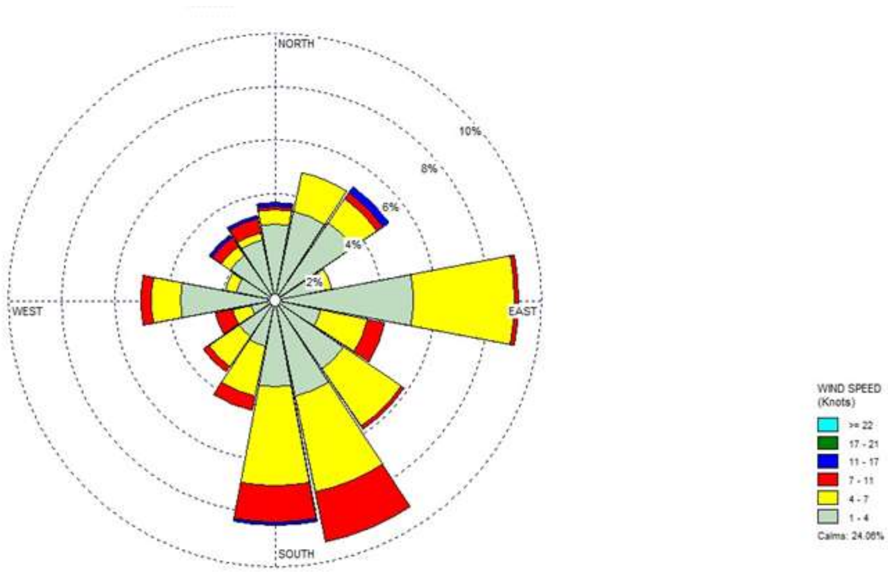

Fig. 3: Wind rose diagram of KLIA meteorological station

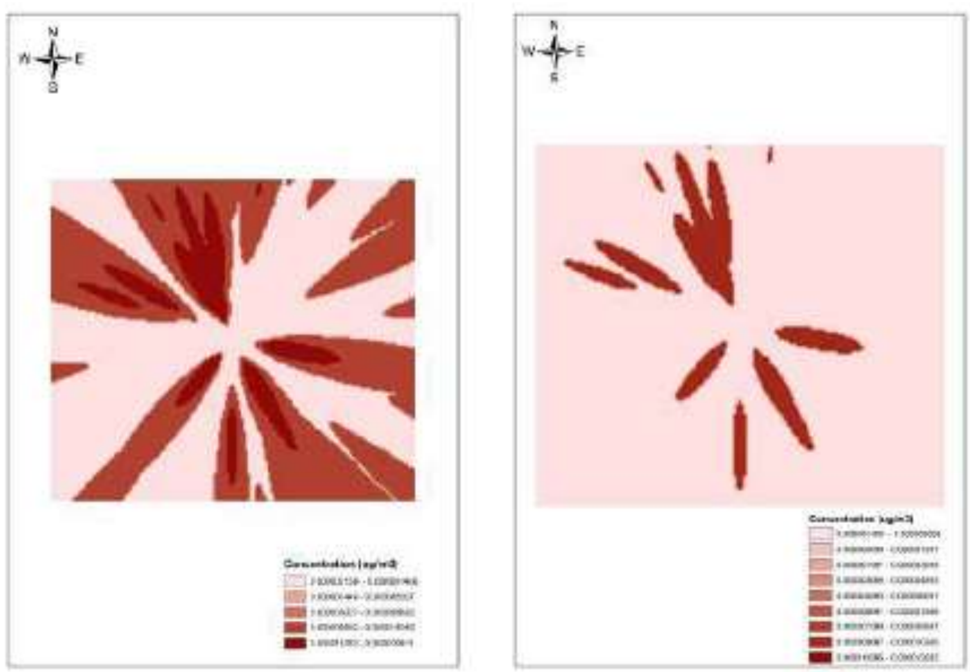

Fig. 4: The dispersion patterns of 1h GLC of Pb and Hg near the incinerator based on reported emission rates (from left to right)

Discussion

This study presents the predicted maximum GLC of heavy metals for example Pb, As, Cd and Hg based on the actual emission rate as well as the emissions imposed on the incineration plant. As presented in table 3, the comparison of recommended ambient air quality guidelines with the maximum GLC of pollutants in different time scales for example 1h, 3h, 8h and 24h demonstrated that the contribution from the plant was significantly low with respect to the recommended ambient limits. None of the predicted maximum GLCs of the pollutants exceed more that 0.003% and 0.2% of their respective limits when the modeling exercise is performed based on the actual emission rates and emission limits. In a study by Morra et al. the human health risk from exposure to air pollutants from some sources of pollution for example a municipal solid waste incinerator and landfill was assessed. The authors showed that the impact of pollution sources on humans and environment was acceptable (20).

As presented in Fig. 2 and 4, the dispersion patterns of pollutants show higher concentrations in the north and northwest direction of the area in accordance with the prevailing wind direction. In fact, the wind rose in Fig. 3 presents the prevailing wind direction from the south and south east which carries the pollution downwind into the north quadrant. Similarly, Zou et al. in their study of predicting SO_2 pollutants using AERMOD in an urban area presented that the increase in the exposure concentration is affected by the predominant wind direction (21). Orloff et al. investigated the concentration of hydrogen cyanide in ambient air near a gold heap leach field in some sample locations where one of them was located in the upwind and the others in the downwind of the predominant wind. The authors found a very low (essentially zero) ambient air cyanide concentrations at the predominantly upwind monitoring station (18).

A higher concentration of pollutants is usually observed vicinity a plant for example within a distance of 0.5 km from the stack which would present a significant impact on the ambient air quality in the industrial or nearby area. The finding suggests that the existing air quality level surrounding the plant will not be significantly influenced by the emission from the plant, even though its emission concentrations were predicted based on the maximum allowable emission limits. Evidently, based on the results of the simulation, the impact of the emission from the plant assuming maximum allowable emission limits do not seem to present any significant deterioration on the level of air quality surrounding the plant. Seangkiatiyuth et al. applied the AERMOD modeling system for environmental impact assessment of NO_2 emissions from a cement complex in Thailand and found that the peak value of NO_2 concentrations occurred nearby the pollution sources for example within the distances of 1 to 5 km from the cement complex compared to the farther distances (22).

On the other hand, the onsite ambient air quality data were gathered based on the existing six monitoring stations, three stations located 100 m radius within the boundary of the hazardous waste complex, while another three are located within 1.5 km away outside the boundary of the complex (Table 5). The data reported to two decimal places with most of the elements had been found to be undetectable for example below the detection limits, except for Pb. The ambient air concentration vicinity the plant is far below the recommended air quality guidelines, thus its impact is remote.

Table 5: Ambient air quality on site measurement near the incinerator compared with the ambient air quality guidelines

Pollutant (ug/m^3)	Ambient air quality on site measurement*	Ambient air quality guidelines
Pb	0.04	1.5
As	<0.01	0.3
Cd	<0.01	2
Hg	<0.01	2

* Source: Detail Environmental Impact Assessment, 2011 (23)

Conclusions

AERMOD air dispersion model was used to predict the ground level concentration (GLC) of heavy metals emission from an incineration plant. The findings indicate that the predicted GLC of the selected metal pollutants were significantly low compared to the recommended ambient air quality guidelines. Thus, the probably impact due to the emission from the incineration plant onto the environment seemed remote. Furthermore, the predicted 1h maximum GLC considering using emission rates based on the limits imposed on the plant in the modeling exercise was still significantly low compared to the ambient air quality guidelines. Therefore, considering the worst scenario, the existing air quality level surrounding the plant is not significantly influenced by the emission from the plant, even though its emission concentrations were at the maximum allowable emission limits.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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References

1. Chang MB, Huang CK, Wu HT, Lin JJ, Chang SH (2000). Characteristics of heavy metals on particles with different sizes from municipal solid waste incineration. *J Hazard Mater*, 79: 229–239.
2. National research council (NRC) (2000). Understanding health effects of incineration. In: Waste Incineration & Public Health. National Academy, Washington, DC, pp. 140–155.
3. Javied S, Tufail M, Khalid S (2008). Heavy metal pollution from medical waste incineration at Islamabad and Rawalpindi, Pakistan. *Microchem J*, 90: 77–81.
4. Kuo JH, Tseng HH, Rao PS, Wey MY (2008). The prospect and development of incinerators for municipal solid waste treatment and characteristics of their pollutants in Taiwan. *Appl Therm Eng*, 28: 2305–2314.
5. Zubero MB, Aurrekoetxea JJ, Ibarluzea JM, Arenaza MJ, Rodríguez C, Sáenz JR (2010). Heavy metal levels (Pb, Cd, Cr and Hg) in the adult general population near an urban solid waste incinerator. *Sci Total Environ*, 408: 4468–4474.
6. Natusch DFS, Wallace JR, Evans CA (1974). Toxic trace elements: preferential concentration in respirable particles. *Science*, 183: 202–204.
7. Hlavay J, Polyak K, Wesemann G (1992). Particle size distribution of minerals phases and metals in dust collected at different workplaces. *J Anal Chem*, 344: 319–321.
8. IARC (1990). Chromium and chromium compounds. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Vol. 49, Chromium, Nickel and Welding. Lyon: International Agency for Research on Cancer.
9. IARC (1993). Cadmium and cadmium compounds. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Vol. 58, Beryllium, Cadmium, Mercury and Exposures in the Glass Manufacturing Industry. Lyon: International Agency for Research on Cancer.
10. Rao ST, Sistla G, Keenan MT, Wilson JS (1980). An evaluation of some commonly used highway dispersion models. *Atmos Environ*, 20: 1095-1103.
11. Sharma N, Chaudhry KK, Rao CV (2004). Vehicular pollution prediction modeling: a review of highway dispersion models. *Transport Review*, 24: 409-435.
12. Patel VC, Kumar A (1998). Evaluation of three air dispersion models: ISCST2, ISCLT2, and SCREEN2 for mercury emissions in an urban area. *Environ Monit Assess*, 53: 259-277.
13. Abdul Wahab SA, Al-Alawi SM, El-Zawahri A (2002). Patterns of SO2 emissions: A refinery case study. *Environ Modell Softw*, 17: 563–570.

14. Taha MPM, Drew GH, Longhurst PJ, Smith R, Pollard SJT (2006). Bioaerosol releases from compost facilities: Evaluating passive and active source terms at a green waste facility for improved risk assessments. *Atmos Environ*, 40: 1156-1169.
15. Bhanarkar AD, Goyal SK, Sivacoumar R, Rao CV (2005). Assessment of contribution of SO2 and NO2 from different sources in Jamshedpur region, India. *Atmos Environ,* 39: 7745–7760.
16. Bhaskar BV, Rajasekhar RVJ, Muthusubramanian P, Kesarkar AP (2008). Measurement and modeling of respirable particulate (PM10) and lead pollution over Madurai, India. *Air Quality, Atmos & Health,* 1: 45–55.
17. Onofrio M, Spataro R, Botta S (2011). The role of a steel plant in north-west Italy to the local air concentrations of PCDD/Fs. *Chemosphere,* 82: 708–717.
18. Orloff KG, Kaplan B, Kowalski P (2006). Hydrogen cyanide in ambient air near a gold heap leach field: measured vs. modeled concentrations. *Atmos Environ,* 40: 3022–3029.
19. United States Environmental Protection Agency (USEPA) (2009). AERMOD implementation guide. Available at: http://www.epa.gov/scram001/7thconf/aermod/aermod_implmtn_guide_19March2009.pdf.
20. Morra P, Lisi R, Spadoni G, Maschio G (2009), The assessment of human health impact caused by industrial and civil activities in the Pace Valley of Messina. *Sci Total Environ,* 407: 3712–3720.
21. Zou B, Wilson J, Zhan F, Zeng Y, (2009). Dgf Orloff KG, Kaplan B, Kowalski P (2006). Spatially differentiated and source-specific population exposure to ambient urban air pollution. *Atmos Environ,* 43: 3981–3988.
22. Seangkiatiyuth K, Surapipith V, Tantrakarnapa K, Lothongkum A (2011), Application of the AERMOD modeling system for environmental impact assessment of NO2 emissions from a cement complex. *J Environ Sci,* 23(6): 931–940.
23. Detail Environmental Impact Assessment: Proposed incineration of clinical waste in the existing Kualiti Alam Modularised Incinerator (KAMI) plant (2011).