Waste Management 79 (2018) 510–515

Contents lists available at ScienceDirect

Waste Management

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

Modeling of dioxin levels in pine needles exposed to solid waste open combustion emissions

Assal Haddad [a,*], Shadi Moqbel [b]

[a] Department of Civil Engineering, American University of Madaba, P.O. Box: 2882, Amman 11821, Jordan
[b] Department of Civil Engineering, The University of Jordan, P.O Box University of Jordan, Amman 11942, Jordan

ARTICLE INFO

Article history:
Received 1 April 2018
Revised 8 August 2018
Accepted 9 August 2018

Keywords:
Open combustion
Solid waste
Dioxin
Regression
Modeling

ABSTRACT

Incomplete open combustion of solid waste produces a range of dioxin compounds which have the ability to accumulate in mediums such as organic soil and leave's wax at levels that are proportional to its ambient concentrations. Biomonitoring of contamination levels in pine needles have been used to assess the severity of atmospheric pollution due to the ability of the needles to store considerable amounts of pollutants including dioxin. Information about the dioxin levels in trees leaves are of an additional value since stored dioxin in leaves can also be conveyed to other animals higher in the food chain, or could migrate to underlying soils because of rain effect. Several biomonitoring studies have been conducted to assess the health impact of local solid waste incinerators, through time consuming and intensive laboratory testing. This study utilizes the results of these previous studies and proposes a statistical regression model that predicts the dioxin concentration in pine needles as function of distance away from emission source, plastic content of burned waste, and time of exposure. To increase the pool of data on which this model is based, 24 pine needle samples affected by a solid waste open combustion site in Amman have been tested at different distances from the emission source, resulting in a total sample size of 43 data points. Solid waste plastic content were obtained from other resources. The fitted nonlinear model had an R-squared value of 89% and a Standard Error Estimate of 0.5. The relationship between the independent variables and the dioxin contamination level appeared to be non-linear. The modeled dioxin concentration was found to be very sensitive to time of exposure, while being less sensitive to distance from emissions source.

1. Introduction

Uncontrolled open burning of Municipal Solid Waste (MSW) results in the production of harmful air pollutants including fine particles, Polycyclic aromatic hydrocarbons (PAHs), heavy metals, and dioxins, due to the incomplete combustion of the fossil origin portion of solid waste like plastic, rubber, and certain type of textiles. Dioxins are semi-volatile organic contaminants that are categorized as persistent organic pollutants (POPs). These chemicals have long half-lives which allow them to travel long distances and accumulate in high concentrations in various mediums. Dioxin and Dioxin-like compounds (DLCs) concentrations in the environment are becoming increasingly important due to the carcinogenic effect they have on humans and animals, in addition to the damage they cause to the reproductive and endocrine systems.

Biomonitoring allows direct and accurate assessment of the degree of risk associated with exposure to different types of air pollution under highly specific local conditions through measurements of pollutant accumulation in sensitive organisms. The accumulation of heavy metals (Pb, Zn, Cu) from traffic emissions in an Algerian town on leaves of rootless plants; Platanus acerofolia, Cypress evergreen Cupressus sempervirens, and Xanthoria parietina have been measured (Maatoug et al., 2012). The levels of heavy metals pollution from automobile parking lots in the second largest city in Nigeria on leaves and barks from different types of nearby trees were investigated (Olajire and Ayodele, 2003). It was found that there was no sufficient evidence that concentration levels of lead in soil affect that in plant tissue; by comparing lead concentrations in leaves of the same species and age grown in two opposite environments (a clean and a heavily polluted city in Philippines) (Cruz et al., 2013). By analyzing leaves properties and heavy metals concentrations in leaves of trees exposed to high density traffic in Iran, effect of air pollution was clear in both the high levels of pollutants concentrations in plant tissues, and in

* Corresponding author.
E-mail addresses: a.haddad@aum.edu.jo (A. Haddad), S.Moqbel@ju.edu.jo (S. Moqbel).

https://doi.org/10.1016/j.wasman.2018.08.020
0956-053X/

the altered leaves anatomy (lower leaf size and stomata density) (Pourkhabbaz et al., 2010).

While there have been numerous studies that have tried to evaluate the atmospheric dioxin contamination caused by open combustion of MSW through biomonitoring, there has been no consistency in the methodology followed. Critical parameters like wind speed and direction, distance from source, topography, temperature, rate of emissions, and waste composition, were never all completely addressed in previous studies of this kind. This study aims at using multiple regression to propose a statistical model that describes dioxin concentration in pine needles as a function of distance to solid waste open combustion source, time interval of exposure, and plastic content of burned waste. Since the model is extremely dependent on data extracted from previous studies, parameters like topography and wind speed and direction were not included in this model due to the total absence of any kind of information related to these parameters in the previous studies. This model can be useful in assessing atmospheric contamination by correlating ambient dioxin concentrations to predicted pine needles concentrations. Due to scarcity of data in literature that addresses the complete set of parameters in question; the sample size needed to be expanded. Hence, 24 samples of pine needles exposed to emissions from open combustion of municipal solid waste of known characteristics were tested at varying directions and distances from emissions source. Missing information from previous biomonitoring studies were obtained from various scientific and governmental sources.

2. Materials and methods

2.1. Data sources

The regression model acquired data from two types of sources; (1) previous studies that investigated the dioxin concentrations in pine trees needles as a cause of MSW open combustion, and (2) current tests carried out additionally as part of this specific study.

2.2. Data from previous studies

Four mutually exclusive previously published studies were used to acquire data to build the regression model. The studies were conducted over a period of ten years (2006–2016) and were located in different countries (except for two studies carried out in China) (Table 1). Although all the studies focused on assessing the effect of solid waste incineration by measuring dioxin concentration in local pine needles, they all lacked a clear description of some of the parameters that were investigated in this study. Studies that tested several samples presented their results in the form of a range of concentrations; hence, their average value was used to represent the entire study. The following is a brief description of the previous work that was used in this study:

(a) CH1: the study was conducted in 2009 (published in 2012) where pine needles samples were collected from 38 cities in China to measure their dioxin concentration, and were found to be in the range of 0.08–22.22 pg/g I-TEQ (Chen et al., 2012). The goal of this study was to establish a relationship between dioxin levels in pine needles and in air. Sampling sites were far from any major industrial plant or major road, except for one site that was located relatively in the vicinity of a solid waste incinerator and a medical waste incinerator (15 pg/g I-TEQ). The study provides coordinates for all its samples, which enabled the estimation of the distance between the sampling location and the incinerator and was found to be approximately 17,000 m. however, the study did not specify both the time of exposure to the incinerator's emissions and any description of the incinerated solid waste. Information regarding the beginning of work of the incinerator and the characterization of the solid waste were acquired from other sources (Hu et al., 2015, and Zhiqiang et al., 2006; respectively).

(b) CH2: the study was conducted in 2013 (published in 2017) where twelve samples of one year and three year old pine needles were collected and tested for dioxin near a solid waste incinerator that was operating for 10 years, and were found to have an average concentration of 24.9 and 51.3 pg/g I-TEQ for the 1 and 3 year old needles, respectively (Chen et al., 2017)]. The aim of the study was to explore variations in dioxin concentrations in different growing years. The study provided no numerical description of the distance between the facility and the sampled trees, and instead, it just described the tested samples as being "in the vicinity" of the incinerator. Hence, samples were assumed to be 100 m away from the emissions source. The study also did not provide any description for the incinerated solid waste, which was accordingly assumed to be similar to the typical solid waste characterization of China (Wang and Nie, 2001).

(c) JP: the study was conducted over the period 1999–2006, where dioxin concentrations were measured in 11 samples of pine needles exposed to 4 years of municipal solid waste incinerators' emissions in Japan. The study found that concentrations were in the range of 0.22–1.30 pg/g I-TEQ (Ikeda et al., 2006). The aim of this study was to assess the impact of the most advanced disposal facilities on the ambient concentrations of dioxin through biomonitoring. Once more, the study only described the tested samples as being "in the vicinity" of the incinerator and where later on (in the regression model) assumed to be 100 m away from the emissions' source. Since the waste characterization was not provided in the study, the typical solid waste composition of Japan was adopted for data points from the study of Pipatti et al. (2006).

(d) CA: the study was conducted in 2000 where eleven sites in Canada were investigated for dioxin background concentrations through measuring dioxin concentrations in pine needles. Only one site was considered in the regression model since it was exposed to emissions from open combustion of electric wires and cables for a period of one year to reclaim the metal inside. The rest of the samples were tested for background pollution that was not directly related to solid waste open combustion. The sample tested near the waste combustion site had a dioxin concentration of 2.21 pg/g I-TEQ (Germain et al., 2001). Since only electric wires were burned, plastic was assumed to be 100% of the

Table 1
Previous biomonitoring studies used in regression calculations.

Country	Sample	Emission source	Reference	Number of samples tested in the previous study
China	CH1	Wuhan Incinerator	Chen et al. (2012)	1
China	CH2	Pearl River Incinerator	Chen et al. (2017)	6
Japan	JP	several incinerators	Ikeda et al. (2006)	11
Canada	CA	Canadian Industrial Park	Germain et al. (2001)	1