

# Occupational health risk assessment of benzene and toluene at a landfill site in Johannesburg, South Africa

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## Abstract

In developing countries land-filling is the most common form of waste management that is practiced. Landfills are known to be anthropogenic sources of air pollutants that have a negative impact on both environmental and human health. People who work on landfill sites are particularly at risk of adverse health effects associated with the inhalation of hazardous air pollutants (HAPs), such as volatile organic compounds (VOCs). Although VOCs only make up between 0.5% and 1% of total landfill gas, they are important due to the high level of toxicity associated with them. Regular air quality monitoring and hazard risk assessments provide important information that can be used in an effort to protect the health and safety of people working in a landfill environment. This is especially important within a developing context as relevant information is limited. In this study an occupational health risk assessment of benzene and toluene was conducted at a landfill in Johannesburg, South Africa. Applying an approach of modelling (using LandGEM) results indicated a significant increase in emission rates over a 90 year period. In addition, ambient air concentrations of BTEX, 100 meters from the landfill, were found to be unacceptable by US EPA air quality recommended standards. Additionally, cancer risk and hazard index calculations of benzene and toluene, of employees on-site, indicated that occupational exposures were above US EPA recommended standards. Thus, it was shown that employees were significantly at risk to adverse health effects associated with inhalation exposure to these HAPs.

*Keywords: occupational health risk assessment, landfill, benzene, toluene.*



## 1 Introduction

In South Africa landfilling is the preferred method for managing Municipal Solid Waste (MSW) (Strachan and Tomaszewski [1]). Landfilling is the process in which MSW products are compacted and disposed of into a landfill. Landfills are a major source of Hazardous Air Pollutants (HAPs) that are known to have adverse health effects on exposed groups of people (Cointreau [2]; Davoli *et al.* [3]). VOCs are produced during anaerobic decomposition of hazardous components of MSW. Although VOCs occur in trace amounts in landfill gas, they are significant in that they are associated with a high level of toxicity at relatively small concentrations (Durmusoglu *et al.* [4]).

Inhaling air pollutants is the most direct exposure pathway to hazardous components on landfills. Air contaminants are able to reach the upper and lower portions of the lungs via inhalation. Inflammation and damage to the lungs and organ tissues occur through exposure to relatively high concentrations of contaminants or alternatively to low concentrations of contaminants over a long period (Elsom [5]; Bridges *et al.* [6]; Ezzati and Kammen [7]; Duarte-Davidson *et al.* [8]; Lindberg *et al.* [9]; Medina *et al.* [10]; Cointreau [2]; Kampa and Castanas [11]; Davoli *et al.* [3]; Durmusoglu *et al.* [4]). Due to this fact, it is imperative to conduct further analysis regarding occupational health, as workers are exposed on a daily basis to these emissions.

### 1.1 Release of VOCs from landfills

While there are many different types of VOCs present in landfill gas which vary significantly amongst different landfills, benzene, toluene, ethyl-benzene and xylenes (BTEX) are some of the most common VOC species present (Allen *et al.* [13]). According to Chiriac *et al.* [14] benzene and toluene gas are the most abundant of the BTEX group found in landfill gas.

Emissions from landfills mainly consist of methane (~50–60%), carbon dioxide (~40%) and various non-methane organic compounds (NMOC's). However, emissions of known or suspected carcinogens and teratogens (VOCs, benzene, vinyl chloride, dioxins, and polycyclic aromatic hydrocarbons) also occur. Emissions containing hydrogen sulphide, mercury vapour, microbial pathogens, dust, and particulate matter are of specific concern (Vrijheid [12]). As these pose concerns regarding health, for workers and residents living in close proximity to landfills, many studies have evaluated their effects. However, these studies have mainly been conducted in North America and the United Kingdom (Vrijheid [12]). Studies have revealed that over 200 gas compounds are found in landfill sites.

In South Africa, the release of VOCs is exacerbated during different seasons. During the winter season a high pressure system is more prevalent, atmospheric conditions are more stable and vertical dispersion of pollutants is weaker. This allows gases to accumulate over the landfill site. During summer, a less dominant high pressure system is prevalent, atmospheric conditions are less stable and vertical dispersion of pollutants is stronger (Dickerson *et al.* [15]).



Seasonal changes in temperature can also influence concentrations of VOCs. Higher temperatures can create conditions that sustain a high level of biological activity in the later stages of decomposition thus generating higher concentration of landfill gas. Cooler temperature in winter can also induce freezing (night) and thawing (day) processes which can disturb the surface upper layer allowing certain gases to escape (Chiriac *et al.* [14]). In addition, seasonal changes in rainfall can significantly influence concentrations of VOCs. Benzene and toluene for example, are removed from the atmosphere via wet deposition. Thus concentrations of benzene and toluene are likely to be lower during periods of high precipitation (Bhailall *et al.* [16]).

Duarte-Davidson *et al.* [8] emphasise that the disposal of benzene and toluene containing items in developing countries is common and often not well controlled, increasing the release of these substances. Municipal waste in South Africa is composed of a number of hazardous components such as: paints, batteries, electrical appliances, fluorescent light bulbs, oils, inks and cleaning products. These hazardous components are subject to a number of processes resulting in the release of hazardous substances in the form of a gas, liquid or solid. Benzene for example, is often used as a solvent for industrial purposes for removal of paints and degreasing purposes. It is frequently used in the production of rubber cements and arts and crafts. Disposal of benzene containing substances such as: building materials, inks, furniture materials and flooring products (glues) in a landfill allows benzene to be released as a component of landfill gas or leachate (Duarte-Davidson *et al.* [8]). Similarly toluene can be released from volatilisation and decomposition of waste that actually contains toluene compounds (paint thinners, solvents, nail polish, etc.).

## 1.2 Health effects associated with exposure to benzene and toluene

Benzene is a well-known carcinogenic component of landfill gas. Studies have shown that exposure to high concentrations of benzene can cause leukaemia, neurological effects, skin problems, respiratory problems and eye problems (Vrijheid [12]; Duarte-Davidson *et al.* [8]; Cointreau [2]; WHO [17]). A high risk of leukaemia can be expected when exposed to concentrations of benzene equal to or above  $160\text{mg/m}^3/\text{year}$  (Duarte-Davidson *et al.* [8]). Potential health effects depend on both concentration and period of exposure. Chronic illnesses are associated with exposure to small concentrations of benzene over a longer period of time. In fact Bridges *et al.* [6] and Vrijheid [12] argue that there should be no standard threshold limit for gases with carcinogenic properties because any level of exposure increases cancer risk.

Unlike benzene, toluene is non-carcinogenic and does not accumulate in body tissues (ATSDR [18]). Despite this, the United States Department of Health and Human Services confirms that exposure to high concentrations of toluene over a long period of time can cause headaches, drowsiness/sleepiness, kidney damage, intensified hearing loss, central nervous system damage, neurological effects, birth defects (including teratogenic effects) and respiratory irritation (Atari and Luginaah [19]).

In South Africa literature regarding health impacts of landfills and their effects on humans is limited and reports that a large proportion of landfill gas comprises of methane and carbon dioxide. Regarding the health effects of gas release from landfills, these epidemiological studies have been conducted in developed countries that follow strict waste management strategies and laws, unlike South Africa. The studies include a range of research from looking at the effects of gas emission on the incidence of cancer (Jarup *et al.* [20]; Pukkala and Pönkä [21]; Russi *et al.* [22]); birth defects and reproductive disorders (Elliott *et al.* [23]; Elliott and Wartenberg [24]; Gilbreath and Kaas [25]; Jarup *et al.* [26]; Kloppenborg *et al.* [27]; Saunders [28]); respiratory diseases (Pukkala and Pönkä [21]).

The aim of this paper is to analyse exposure and inhalation risk of occupational workers at a landfill in South Africa. It will outline the methodology used to analyse a preliminary occupational health risk assessment conducted in a pilot study in Johannesburg. The study focuses on occupational health risks with exposure to benzene and toluene gas within a developing context.

## 2 Background

In South Africa waste is managed according to the minimum requirements laid down by the Government in the National Waste Management Strategy (NWMS) and the National Environmental Management Waste Act (Act 59 of 2008).

South Africa, a developing country, is ahead when compared to other African countries in terms of formally converting open dump sites into landfills since the first Minimum Requirements for Landfilling Waste was published in 1994. The Minimum Requirements maintains that a landfill should be classified according to characteristics of waste types, size of waste stream and climatic water balance (Strachan and Tomaszewski [1]). As a result South Africa is one of the few African countries that have a suitable framework for managing waste efficiently. However, landfill gas management practices in South Africa are still poor compared to most developed countries MSW landfills.

### 2.1 Site description

The study site is Turffontein, south of Johannesburg. The landfill first started accepting waste in 1930 (the site first served as an old gold mine tailings dam, or slimes dam, prior to 1930). It is predicted to close in 2031, and currently has a surface area of 124 hectares. The site is currently operated by the local municipality, Pikitup Ltd. It is classified as a GLB (general, large waste, no significant leachate) landfill site that is situated upon layers of shale, clay and sandstone. The site is surrounded by a combination of residential and industrial areas.

### 3 Methodology

For this study a combined approach was employed, using historical landfill composition/amount data to model landfill gas emissions, and measured ambient concentrations of benzene and toluene to calculate current cancer risk and hazard risk for benzene and toluene. Landfill staff interviews were used to obtain data on current and cumulative exposure to landfill gas emissions.

#### 3.1 Landfill Gas Emissions Model (LandGEM)

Benzene and toluene gas emission rates were estimated using the Landfill Gas Emissions Model (LandGEM V7.0). Input parameters were chosen based on site characteristics. Hence co-disposal of hazardous and non-hazardous waste was assumed. This was due to the fact that the site first served as a gold mine slimes dam prior to a waste disposal site. Default values for methane generation rate constant ( $k$ ) and the methane generation potential ( $L_0$ ) were used (Chalvatzaki and Lazaridis [30]).

Estimates of landfill gas production rates were based on yearly solid waste acceptance rates for the period of 1930–2010. Waste fractions (kg) were provided for by Pikitup for the period of 2003–2010 (for the period 1930–2002 rates were extrapolated).

#### 3.2 Risk calculations

Benzene and toluene are important VOCs present in landfill gas emissions because of the high level of toxicity associated with them. Due to the fact that benzene is a carcinogenic agent (Group A) and toluene is a non-carcinogenic agent (Group D); both cancer risk and hazard risk (associated with the inhalation of air pollutants) calculations were done for 10 individual employees to evaluate the effect of each pollutant respectively. Individual calculated cancer risk and hazard risk values were compared with US EPA acceptable standards.

To calculate cancer risk eqn (2) was applied, whereas eqn (3) was used to evaluate hazard risk:

$$\text{Cancer risk} = \text{Intake (I)} \times \text{carcinogens potency factor (CPF)} \quad (2)$$

$$\text{Hazard risk} = \text{Intake (I)} / \text{reference dose (RFD)} \quad (3)$$

CPF and RFD standard values were used [benzene  $0.029 \text{ mg kg}^{-1} \text{ day}^{-1}$  and toluene  $1.43 \text{ mg kg}^{-1} \text{ day}^{-1}$ ] (Durmusoglu *et al.* [4]).

To calculate the intake eqn (4) was utilised:

$$I = (C.CF.IR.EF.ED) / (BW.AT) \quad (4)$$

where the parameters can be defined as:

- C is the contaminant concentration (average eight-hourly concentrations were collected using the SYNSPEC Spectras GC 955 analyser and measured continuously per season. Data was provided for by the

University of the Witwatersrand's former Climatology Research Group for the late autumn/winter period of 2010) [ $\mu\text{g}/\text{m}^3$ ];

- CF is the conversion factor [ $1 \text{ mg}/1000\mu\text{g}$ ];
- IR is the inhalation rate (US EPA standard) [ $20\text{m}^3/\text{day}$ ];
- EF is the exposure frequency [ $\text{day}/\text{year}$ ];
- ED is the exposure duration [years];
- BW is body weight (US EPA standard) [70kg];
- AT is the averaging time (exposure averaged over life time/ average life expectancy for male and female) [days].

### 3.3 Interviews

Ten interviews were conducted in order to provide information pertaining to individual input variables such as age, sex, exposure frequency and exposure duration. Where data were limited due to ethical restrictions US EPA standard values were used [for body weight (70kg) and inhalation rate ( $20\text{m}^3/\text{day}$ )] (Durmusoglu *et al.* [4]). In addition it was assumed that all employees worked a standard of eight hours per day and received a minimum of 21 days leave each year. More detailed evaluation of confounding factors was beyond the scope of this study.

Thus to calculate exposure frequency (EF) eqn (5) was used:

$$[52 * (\text{number of days worked}/3)] - \text{Number of days leave} \quad (5)$$

where values represent:

- 52 = weeks in a year
- 3 = 24 hours in a day/8 hours of work

## 4 Results and discussion

### 4.1 Benzene and toluene emission rates

Modelling of HAPS from landfills can provide insightful projections for future conditions, which may aid in the minimisation of potential implications before the effects become irreversible. Modelled emission rates for benzene and toluene show a significant increase for 1930–2020 at the study site (the results are based on expected future waste fractions) (Figure 1). Rates of production for benzene and toluene rapidly increased from 1970; and are expected to reach a peak of 4.89 Mg/year and 89.00 Mg/year respectively in 2020. There is little information describing emission rates of benzene and toluene over landfills in South Africa. Nonetheless, the projected maximum production rate of benzene is comparable to that of the Ano Liosia landfill in Athens in the results of Paraskaki and Lazaridis [30]. However, there was no active gas collection system installed at Ano Liosia and one only recently installed at the Johannesburg landfill.

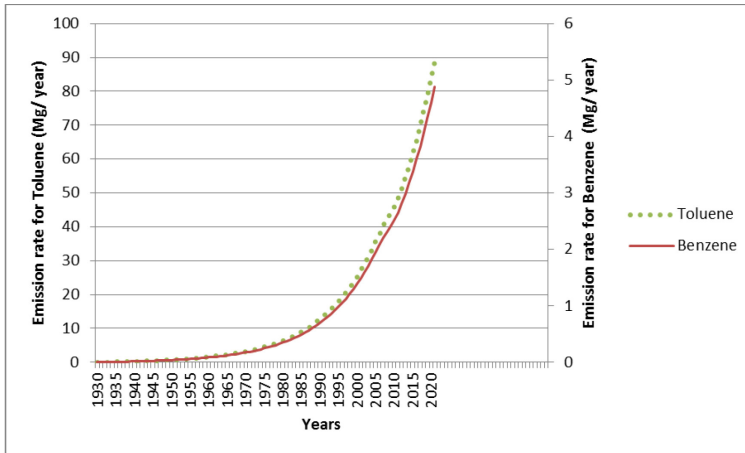


Figure 1: Modelled emission rates of benzene and toluene for the landfill site for 1930–2020. There is a slight variation in emission rates of the gases as anaerobic decomposition of benzene occurs at a slower rate than toluene.

At the landfill there has been no gas collection system for the period of 1930–2011. Landfills with no active gas collection systems are associated with higher emission rates of VOCs compared to landfills with an active gas collection system (Di Bella *et al.* [31]). Over time VOCs become less prevalent and methane and carbon dioxide are more prevalent (Chiriac *et al.* [14]). Thus VOCs only account for a small portion of landfill gas that is being produced. However, pollutant concentrations for benzene and toluene at the landfill in 2010 were found to be ten times higher than that of US EPA's 8 hour recommended standards. Benzene and toluene recommended standards are  $166.1008\text{mg/m}^3$  and  $753.71\text{mg/m}^3$ , while pollutant concentrations were found to be  $1987.08\text{mg/m}^3$  and  $9446.71\text{mg/m}^3$  respectively for the year. It can be inferred that people exposed to higher emission rates of VOCs are possibly at risk of adverse health effects (Bridges *et al.* [6]).

#### 4.2 Cancer risk and hazard risk calculations

In order to assess whether these emissions would have an effect on employees, the risks were evaluated. All employees interviewed had been employed for a minimum of two years. Respondents two and four had both worked on the site for 25 years. All employees worked at least five days a week. Only respondents two and three stated that they worked on site six days a week. Thus based on the above information, both respondents two and three had a maximum exposure frequency of 83days/year each (Table 1).

Risks were based on the assumption that pollutant concentrations were linearly comparable to modelled emission rates. Thus, using base line concentrations of benzene and toluene of  $1987.08\text{mg/m}^3$  and  $9446.71\text{mg/m}^3$

respectively for 2010; exposure of each respondent was scaled using the modelled emissions. Cancer risks were characterised for each respondent exposed to benzene emissions on site and were found to be above the US EPA standard of 0.0004 (Durmusoglu *et al.* [4]), for all respondents (Figure 2). Respondents two and four both had unacceptably high cancer risks of 1.028795 and 0.813946 respectively, while other respondents had a level of risk marginally below respondents two and four.

Table 1: Attribute information for interviewees.

RESPONDENT NUMBER		1	2	3	4	5	6	7	8	9	10
ATTRIBUTE	Exposure frequency (day/year)	65.67	83.00	83.00	65.67	65.67	65.67	65.67	65.67	65.67	65.67
	Exposure duration (years)	2.5	25	2.5	25	7.5	2.5	7.5	7.5	7.5	2.5
	Age	40	51	36	50	32	32	56	32	27	28
	Sex	f	m	m	m	m	m	m	m	m	m

Hazard risks (non-cancer risk) were above the US EPA standard of 1 (Durmusoglu *et al.* [4]; Tunsaringkarn *et al.* [32]) for all respondents (Figure 3). Therefore hazard risks for all respondents were considered unacceptable. Thus it was found that the landfill in Johannesburg poses a major occupational risk to all employees. In addition estimates for 2020, based on modelled results, indicated that cancer risks range from 1.11–4.53 and hazard risks range from 262.50–840.29 for employees in service for the additional eight years (the significant range is due to the fact that years of employment range from an expected 10.5–33 years of service at the landfill in 2020). This implies increased risks of 98% from 2010 baseline results.

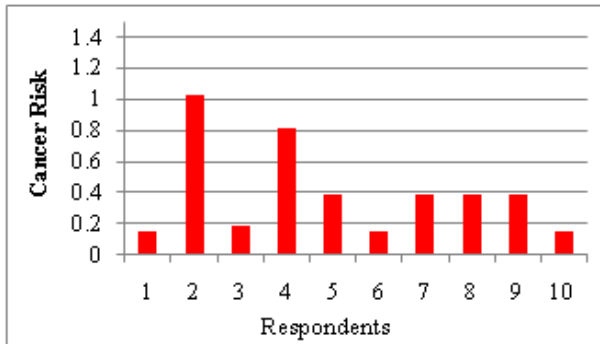


Figure 2: Cancer risk for employees exposed to benzene. The US EPA standard is 0.0004, indicating that cancer risk is above the guideline value for all employees.



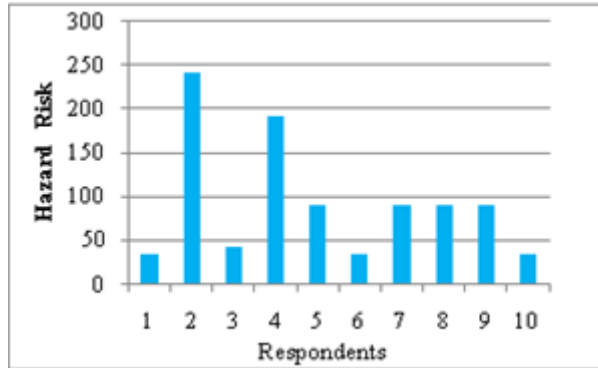


Figure 3: Hazard risk for employees exposed to toluene. The US EPA standard is 1, indicating that cancer risk is above the guideline value for all employees.

It has been argued in many studies that people who have been exposed to concentrations of HAPs within acceptable air quality standards are safe from adverse health effects (Elsom [5]; Bridges *et al.* [6]; Duarte-Davidson *et al.* [8]; Medina *et al.* [10]; Cointreau [2]; Kampa and Castanas [11]). However, as shown all respondents, people who have been exposed to above acceptable levels of benzene over any period of time are at risk to adverse health effects. Duarte-Davidson *et al.* [8] show that repeated exposure to benzene can cause acute non-lymphocytic leukaemia because benzene is able to accumulate in the body. Furthermore, they suggest that people who are repeatedly exposed to benzene are at risk of problems with production of bone marrow, white blood and red blood cells, cancer and chromosomal malformations (Duarte-Davidson *et al.* [8]).

Toluene on the other hand is not able to accumulate in the body and within 12 hours after exposure 75% of toluene is removed from the body (ATSDR [18]). Therefore, people who are exposed to below threshold concentrations of toluene are safe from adverse health effects. Conversely, with the high level of calculated hazard risks for each respondent, repeated exposure to toluene can cause permanent damage to heart, kidneys, liver, lungs and central nervous system (Mckeown [33]). Furthermore, calculated cancer and hazard risks are limited in that assumptions were made based on US EPA standard values with respect to body weight, inhalation rate and amount of hours worked and could be underestimated. Similarly confounding factors such as smoking, level of fitness or exposure to other sources of benzene and toluene and alternative exposure routes (digestion or skin absorption) were not considered as this was beyond the scope of this study. There is a need for further epidemiological studies investigating possible health effects of exposed occupational workers to benzene and toluene at this landfill site; however estimated risks are very high.

## 5 Conclusion

In conclusion landfill sites are a major source of HAPs. People who work on landfills are exposed to HAPs via the inhalation of landfill gas. People who are exposed to above standard concentrations of VOCs are at risk of adverse health effects. In developing countries information of this sort is limited. Thus an occupational health risk assessment was conducted for a single landfill site in Johannesburg, South Africa.

According to the model, production rates of benzene and toluene were shown to have increased since 1930, while pollutant concentrations in 2010 were above all US EPA recommended standards (24 hour; 8 hour and annual recommendations). Additionally, cancer risk and hazard risk were characterised for employees exposed to benzene and toluene. All respondents had unacceptable cancer and hazard risks. Thus, it was shown that employees were significantly at risk to adverse health effects associated with inhalation exposure to these HAPs.

However, cancer risks and hazard risk calculation could be under- or overestimated due to the limited amount of data that could be obtained, and the fact that results were based on an assumption that modelled and measured concentrations were linear. Thus further research needs to be done to accurately evaluate cancer risks and hazard risks associated with occupational exposure to benzene and toluene at the landfill site.

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