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The impact of a landfill fire on ambient air quality in the north: A case study in Iqaluit, Canada

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ABSTRACT

A large landfill fire occurred in Iqaluit, Canada in spring/summer 2014. Air quality data were collected to characterize emissions as well as potential threats to public health. Criteria pollutants were monitored ($PM_{2.5}$, O_3, NO_2) along with dioxins/furans, polycyclic aromatic hydrocarbons, and volatile organic compounds. Median daily dioxin/furan concentrations were 66-times higher during active burning (0.2 pg/m^3 Toxic Equivalency Quotient (TEQ)) compared to after the fire was extinguished (0.003 pg/m^3 TEQ). Other pollutants changed less dramatically. Our findings suggest that airborne concentrations of potentially harmful substances may be elevated during landfill fires even when criteria air pollutants remain largely unchanged.

1. Introduction

Iqaluit is the largest city in the Canadian territory of Nunavut and is home to approximately 7000 people. The city is located near the inner most end of Frobisher Bay and the city's landfill site is located across the bay at a distance of approximately 2 km. Between May and September 2014, a large smoldering landfill fire occurred through spontaneous combustion in Iqaluit prompting response from local, territorial, and federal health and environment officials aimed at characterizing the potential impact of the fire on air quality and public health. Waste separation was not practiced in Iqaluit at the time of the fire and as a result the landfill contained a wide range of materials including plastic/rubber, wood/paper, and metal waste. Landfill fires are known to emit a variety of pollutants (Chrysikou et al., 2008) and previous studies have examined soil contamination following such fires (Vassiliadou et al., 2009). However, we are not aware of any published reports that have characterized the impact of landfill fires on ambient air quality in Northern Canada or elsewhere. This is an important issue as waste management practices often differ from southern locations owing to unique challenges faced in northern regions. This report describes the impact of the Iqaluit landfill fire on ambient air quality during spring/summer 2014; to our knowledge this is the first study to provide quantitative data on the impact of a landfill fire on air quality in Northern Canada.

2. Materials and methods

2.1. Air pollution monitoring

Ambient air pollutants were monitored at 4 sites in Iqaluit between June and October, 2014 in order to capture potential spatial variations in pollutant concentrations (Fig. 1). This period included approximately 3 months of active burning, a two week

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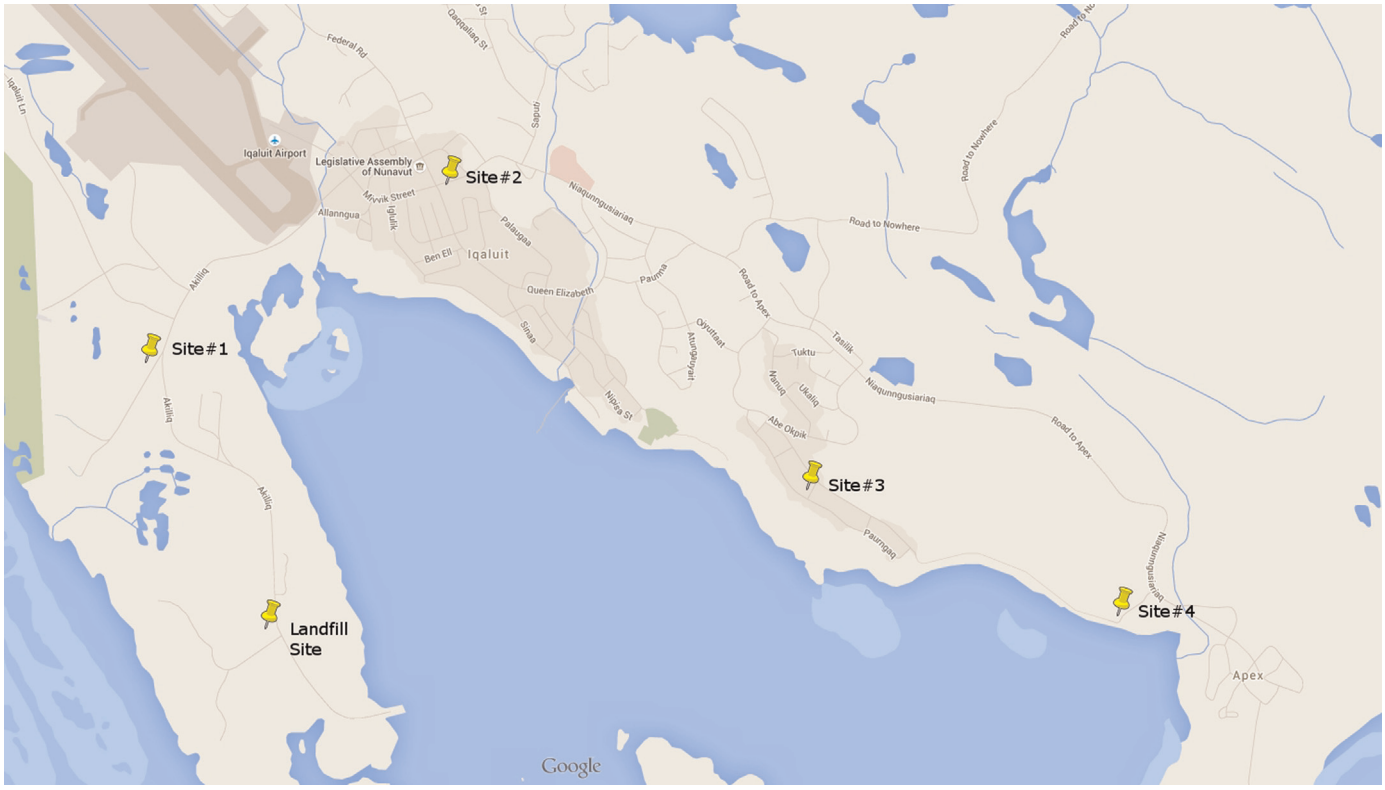

Fig. 1. Air monitoring sites in Iqaluit, Canada. Distances from the landfill fire were as follows: Site 1—1.2 km; Site 2—1.9 km; Site 3—2.4 km; Site 4—3.8 km.

extinguishing period in September 2014, and approximately one month of post-fire monitoring. Air monitoring data were not available prior to the fire. Sites were between 1.2 and 3.8 km from the landfill and their sites were selected to capture potential population exposures (as opposed to plume concentrations in close proximity to the landfill). The landfill site was approximately 5500 m^2 in size and in places was up to 12 m deep (i.e. roughly the size of a football field and 4-stories deep).

A number of air pollutants were monitored in response to the landfill fire but not all pollutants were monitored at each site. Continuous real-time data for fine particulate matter ($PM_{2.5}$) (nephelometry), NO_2 (chemiluminescence), and O_3 (ultraviolet photometry) were collected using an Air Pointer Instrument (MLU/recordum, Austria) located at Site 3 approximately 2.4 km from the fire. Sulfur dioxide and carbon monoxide were also monitored using the Air Pointer Instrument but concentrations were low and near the method detection limits and thus are not reported. Meteorological data (e.g. ambient temperature, wind speed) were also recorded at Site 3 using the Air Pointer instrument. Other pollutants including $PM_{2.5}$ metals and polychlorinated biphenyls (PCBs) were monitored but are not reported as concentrations were generally below method detection limits (i.e. 61% of $PM_{2.5}$ metals samples and 55% of PCB samples were below method detection limits). Twenty-four hour $PM_{2.5}$ metals samples were collected on 47 mm Teflon filters (~24 m^3/sample) using a Thermo Scientific Partisol 2000 monitor with subsequent analysis by energy dispersive x-ray fluorescence (Environment Canada Method 6.09/3.5/M) and inductively coupled plasma mass spectrometry with water extraction (Environment Canada method 6.10/3.0/M). A complete list of compounds monitored is available in the Supplemental material section.

Daily mean (i.e. 24 h) volatile organic compound (VOCs) and polycyclic aromatic hydrocarbon (PAHs) concentrations were collected at all 4-sites on a 2 day cycle (i.e. every second day). VOC samples were collected using 24-h SUMMA (6 L) canisters with subsequent analysis by gas chromatography–mass spectrometry (GC–MS) (U.S. EPA Method TO-15). PAH samples (combined particle and gas phase) were collected using URG personal pesticide samplers at a flow rate of 4 l/min (~5.76 m^3/sample) with subsequent analysis by GC–MS (U.S. EPA Method TO-13A). Data for benzene and benzo(a)pyrene (BaP) are presented below to represent VOCs and PAHs respectively, as the chronic health risks of these are well characterized. Daily mean dioxin/furan concentrations (combined particle and gas phase) were collected from three separate locations (Sites 1–3) throughout the monitoring period on a schedule of 1 sample every 6 days using HiVol samplers at a nominal flow rate of 500 l/min (~720 m^3/sample) with subsequent analysis by gas chromatography–high resolution mass spectrometry (GC–MS) (ISO 17025 Accredited Environment Canada Method 8290A). PCB samples were collected from the same sites (using the same samples) with subsequent analysis by GC–MS (Environment Canada methods 3.04/2.9/M and 3.03/5.1/M). Samples were collected for approximately 3 weeks at Site 2, one month at Site 3, and then simultaneously at Sites 1 and 3 until the end of monitoring. Technicians also had the option of adding additional monitoring days for dioxins/furans if they felt that smoke was impacting Iqaluit on a day not scheduled for sampling. HiVol samples were analyzed for 17 separate dioxin and furan compounds; these compounds were used to derive Toxic Equivalency Quotients (TEQ) for total dioxins/furans using Toxic Equivalent Factors from the World Health Organization (Van den Berg et al., 2006). The newly proposed Ontario Ambient Air Quality Criterion (24 h average: 0.1 pg/m^3 TEQ) was used to interpret dioxin/furan concentrations and is based on animal evidence suggesting a detrimental impact of maternal exposures during pregnancy on fertility in male offspring (Faqi et al., 1998; Ontario Ministry of the Environment, 2011). This standard will take effect in Ontario on July 1, 2016. Available standards for benzene and benzo(a)pyrene were designed to minimize cancer risk from exposures occurring over a lifetime; therefore, these standards were not relevant for

assessing the immediate public health impacts of short-term changes in ambient concentrations occurring as a result of the fire.

2.2. Statistical analysis

Descriptive statistics were compiled for all pollutants according to the status of the landfill fire including the active burning period, the extinguishing period, and after extinguishing. Descriptive data were also compiled across monitoring sites for pollutants measured simultaneously at multiple locations. Mean differences (and 95% confidence intervals) between ambient pollutant concentrations (pooled across all sites) during and after the fire were calculated using two sample *t*-tests with unequal variances. Multivariable linear regression models were also examined to estimate the impact of the landfill fire on regional air quality adjusting for mean daily wind speed and direction. In these models, the dependent variable was the natural logarithm of mean daily pollutant concentration and independent variables included a continuous term for mean daily wind speed, a categorical variable for wind direction (four quadrants), and an indicator variable for fire status (active burning/extinguished). Random-effect linear regression models were used for air pollutants monitored at multiple sites; a random intercept for site was included in these models to account for the correlations between repeated measures collected within sites. All analyses were conducted using the statistical software packages STATA (v11; StataCorp LP, USA) and R (version 2.15; R Core Team).

3. Results

Air monitoring data were collected in Iqaluit between June 14 and October 14, 2014. Ambient temperatures ranged from −4.5 to 15 °C with a mean temperature of 5.6 °C. The average wind speed during monitoring was 1.6 m/s (range: 0.042–6.1) and was predominately from the north-west (50%) or south-east (27%); both of these wind directions would tend to carry emissions away from the most populated regions of Iqaluit. A south-west wind carried emissions directly towards Iqaluit approximately 10% of the time.

Descriptive data for ambient air pollution concentrations are shown in Table 1. During the fire, ambient concentrations of benzene and dioxin/furans were most highly correlated ($r=0.91$) whereas BaP was not correlated with benzene ($r=0.03$) or dioxins/furans ($r=-0.02$). The limits of detection were approximately 5 ng per sample for BaP and 0.001–10.3 fg per sample for total dioxins/furans. The limit of detection for benzene was 0.024 μg/m^3. Uncertainty estimates (i.e. precision) were 25% for BaP, 14% for total dioxins, 22% for total furans, and 10% for benzene.

In general, daily median concentrations of $PM_{2.5}$, NO_2, and O_3 were not dramatically impacted by the fire although short-term spikes in hourly average $PM_{2.5}$ levels were apparent when the wind was blowing from the landfill site. Specifically, hourly average $PM_{2.5}$ concentrations were as high as 85 μg/m^3; however, the overall median hourly concentration was 2.29 μg/m^3. $PM_{2.5}$ concentrations never exceeded the 24-h Canadian Ambient Air Quality Standard of 28 μg/m^3. Conversely, ambient concentrations of benzene and dioxins/furans were clearly impacted by the fire. The increase in airborne concentrations of dioxins/furans was particularly notable as the median concentration (across all sites) during the fire was more than 66 times higher than the median value measured after the fire was extinguished. During the active burning period, ambient concentrations often exceeded the Ontario Ambient Air Quality Criterion of 0.1 pg/m^3 TEQ although concentrations fluctuated somewhat with lower values tending to

Table 1
Descriptive statistics for 24 h air pollution data collected in Iqaluit during and after the landfill fire.

Pollutant	Landfill fire status						Mean difference (95% CI)[a]	Percentiles for Canadian ambient air quality data (1999–2008)[b]		
	Active burning		During extinguishing		Extinguished			10th	50th	90th
	Mean	Median (Range)	Mean	Median (Range)	Mean	Median (Range)				
$PM_{2.5}$ (μg/m^3)	4.61 $n=77$	3.40 (0.61–16.35)	2.32 $n=17$	1.94 (0.76–7.00)	3.55 $n=29$	2.66 (0.97–10.00)	0.64 (−0.52, 1.8)	3	6	13
NO_2 (ppb)	1.23 $n=77$	1.00 (0.045–3.98)	1.13 $n=17$	1.31 (0.32–1.80)	1.70 $n=29$	1.53 (0.15–4.18)	−0.48 (−0.96, −0.0082)	3	7	20
O_3 (ppb)	21.8 $n=77$	22.13 (12.68–32.03)	27.4 $n=17$	27.84 (21.20–32.96)	28.3 $n=29$	29.31 (17.37–34.96)	−5.5 (−7.4, −3.5)	8	24	41
Benzene (μg/m^3)	1.13 $n=143$	0.51 (0.052–7.65)	0.290 $n=28$	0.26 (0.086–1.15)	0.163 $n=10$	0.15 (0.084–0.25)	0.83 (0.62, 1.0)	0.30	0.62	1.30
Benzo(a)pyrene (ng/m^3)	0.303 $n=144$	0.068 (0.00–5.95)	0.100 $n=32$	0.067 (0.014–0.47)	0.245 $n=14$	0.071 (0.0–1.79)	0.020 (−0.26, 0.30)	0.02	0.07	0.26
Dioxins/FuransTEQ (pg/m^3)	0.382 $n=33$	0.2 (0.002–4.95)	0.0407 $n=10$	0.025 (0.003–0.13)	0.0047 $n=10$	0.003 (0.001–0.01)	0.30 (0.062, 0.53)	0.010	0.016	0.049

[a] Mean difference between active burning (including the extinguishing period) and the extinguished period.
[b] Environment Canada, 2013; TEQ, Toxic Equivalency Quotients. Data reflect all sites combined if a pollutant was monitored at multiple sites.

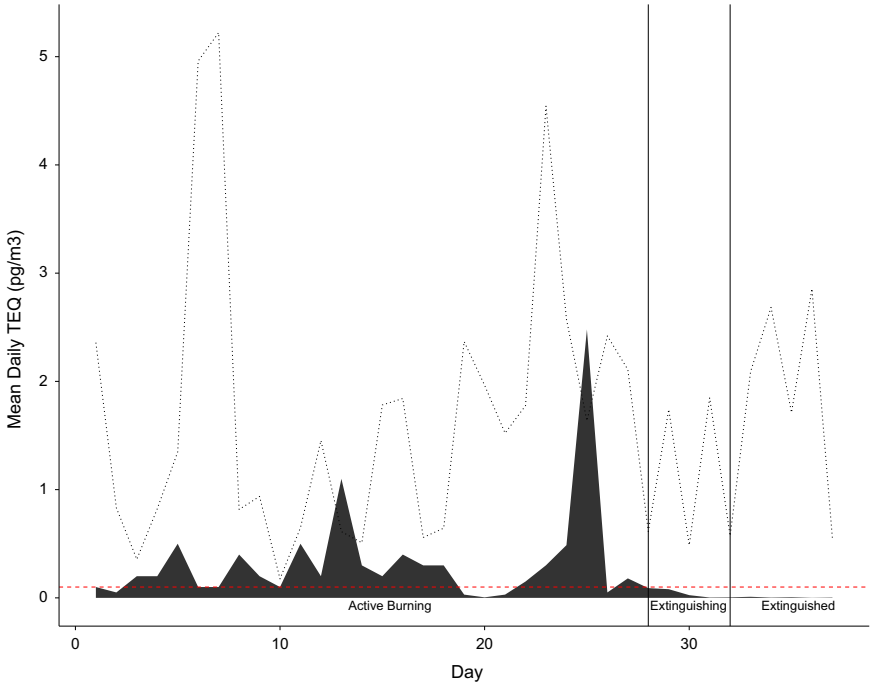

Fig. 2. Daily time trend in mean dioxin/furan TEQ values (averaged over all sites) ($n=53$). The dotted line indicates mean daily wind speed (m/s) and the red horizontal line indicates the Ontario Ambient Air Quality Criterion for dioxins/furans (24 h average: 0.1 pg/m^3 TEQ).

occur at higher wind speeds (Fig. 2). As expected, dioxin/furan concentrations tended to be greater at sites closer to the landfill fire with mean TEQ values of 0.66 pg/m^3, 0.22 pg/m^3, and 0.15 pg/m^3 observed at Sites 1, 2, and 3 respectively. In addition, the highest daily value of 4.95 pg/m^3 TEQ was observed at Site 1 which was closest to the fire. A similar trend of increasing concentration with increased proximity to the landfill fire was also apparent for benzene with values of 2.2 μg/m^3, 0.78 μg/m^3, 0.61 μg/m^3, and 0.33 μg/m^3 observed during active burning for Sites 1–4, respectively. Daily mean benzene ($r=0.45$) and dioxin/furan ($r=0.45$) concentrations were only weakly correlated to $PM_{2.5}$.

Dioxin/furan and benzene concentrations decreased quickly once the extinguishing process began; once the fire was extinguished median concentrations of these pollutants decreased to below the 10th percentiles of values observed across Canada between 1999 and 2008 (Environment Canada, 2013). In hierarchical linear regression models, the indicator variable for active burning was associated with a 2.70 (95% CI: 1.58, 3.82) unit increase in log (TEQ) and a 1.33 (95% CI: 0.739, 1.92) unit increase in log(benzene).

4. Discussion and conclusions

There are surprisingly few published reports of the impact of landfill fires on ambient air quality and to our knowledge this is the first study to evaluate the impact of a landfill fire on ambient air quality in northern Canada. In general, daily mean concentrations of criteria air pollutants were not dramatically impacted by the landfill fire but potentially toxic substances including benzene and dioxins/furans were clearly elevated as a result of the fire. Moreover, levels of dioxins/furans exceeded available guidelines based on toxicological evidence suggesting decreased fertility in the male offspring of mothers exposed to dioxins during pregnancy (Faqi et al., 1998). Public health messaging was issued at the very start of the fire and throughout the burning/extinguishing period advising citizens to avoid exposure to smoke from the landfill fire.

While our findings provide important information regarding the impact of landfill fires on ambient air quality, it is important to note that continuous monitoring data were not collected for most pollutants and thus the concentrations presented may underestimate values in some locations if the plume happened to miss the monitoring stations or if peaks occurred on days that were not monitored. In general, our findings highlight the fact that airborne concentrations of potentially harmful substances may be elevated during landfill fires even when criteria air pollutants including $PM_{2.5}$ remain within acceptable levels. This was particularly true for airborne concentrations of dioxins/furans which experienced increases of more than an order of magnitude and returned to background concentrations shortly after the fire was extinguished.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.06.018.

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