Inventory of chlorinated dioxin and furan sources and releases in Potchefstroom, South Africa

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SOUTH AFRICA RATIFIED THE STOCKHOLM Convention on Persistent Organic Pollutants in 2002, and has to formulate a national implementation plan that includes an inventory of sources and releases of these chemicals. An investigation of polychlorinated dibenzo-*p*-dioxin, polychlorinated dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) was conducted in the Potchefstroom area, using the UNEP Toolkit. These sources, on which negligible information was available, were identified by means of questionnaires and interviews, and the releases quantified using default emission factors. The total estimated release of PCDD/Fs in the study area was calculated as 0.396 g TEQ(toxic equivalency quotient)/yr. The highest amounts were generated from sewage and sewage treatment (0.120 g TEQ/yr) and waste incineration (0.111 g TEQ/yr). This is the first such inventory conducted in this country, and has identified potential sources for which emission factors could be refined under South African conditions.

Introduction

Persistent organic pollutants in the environment can be divided into two main categories: those generated intentionally as manufactured products [such as DDT and polychlorinated biphenyls (PCBs)] or process intermediates [for example, hexachlorobenzene (HCB)], and those released as incidental by-products of anthropogenic activities [such as polychlorinated dibenzo-*p*-dioxin and polychlorinated dibenzofurans (PCDD/Fs) and dioxin-like PCBs].[1] The study reported here focused on PCDD/Fs and PCBs. PCDD/Fs and dioxin-like PCBs are by-products of various industrial and thermal processes, especially those involving chlorinated chemicals.[2] On the other hand, PCBs are manufactured in great quantities and persist as a result of their high chemical stability, low flammability, good heat conduction, high dielectric constant and low electrical conductivity.[3]

South Africa ratified the Stockholm Convention on Persistent Organic Pollutants (POPs) on 4 September 2002.[4] As a consequence, the country is expected to formulate a national implementation plan (NIP) in accordance with the convention's requirements.[5] To formulate a plan, some critical steps should be taken:[6]

- Compiling preliminary inventories of the sources and releases of POPs.
- Preparing an action plan to reduce the unintentional releases of these compounds.
- Assessing the possible occurrence of stockpiles that contain POPs waste or products contaminated with these chemicals.
- Establishing a mechanism to identify sites contaminated with POPs.
- Encouraging broad-based community participation to facilitate information exchange and raising awareness of these chemical hazards.

Compiling a national inventory is a crucial part of an NIP. To this end, we have drawn up an initial inventory for the Potchefstroom area. This involved the systematic screening of industrial and non-industrial processes as possible sources of POPs; and estimating annual releases of these chemicals and future trends.[7,8] The inventory is intended to inform recommendations on interventions to reduce or eliminate releases in the future. With this project, we established the first PCDD/Fs and PCBs inventory for southern Africa.

Potchefstroom is located in the North West province of South Africa. It is not a major industrial centre. The university town's main activities include service industries, a fertilizer plant as well as a brewery. Its other industries are small and their contribution to the generation of dioxin-like chemicals is expected to be from boilers and brick-manufacture. Potchefstroom's population, as reported in the 2001 census, is nearly 116 300.[12] The town is divided into three main residential areas: a high-density residential area, Ikageng, with a population of nearly 62 000; Promosa with a population of nearly 11 000; and Potchefstroom itself, a more affluent, lower density area, with a population of nearly 44 000. Lighting is predominantly from electricity, but candles are also used by many. No data are available on the use of coal and paraffin for lighting, heating and cooking, yet these may contribute significantly to TEQ releases, when judged by the amount of smoke generated in the evenings in Ikageng. These values are almost impossible to estimate because of the level of uncertainty.

Methods

The list of chemicals was drawn up using the guidelines in the United Nations' Environmental Programme (UNEP)'s *Standardized toolkit for identification and quantification of dioxin and furan release.*[9] The guidelines recognize ten major source categories, of which nine produced quantifiable data for the Potchefstroom inventory (Table 1). The contribution of each source is reported in terms of TEQ (toxic equivalency quotient) values, which is the international measure for relating the relative toxicity of dioxin/furan congeners to the toxicity of the most toxic. In this approach, toxic potencies of a mixture of dioxins and dioxin-like chemicals are expressed relative to the benchmark dioxin, 2,3,7,8-TCDD, since it is the most potent.[10,11]

We compiled the POPs inventory as follows: we identified the most likely sources in the Potchefstroom area through literature reviews, interviews, and local knowledge; gathered information by distributing questionnaires to relevant industries (as well as from follow-up inquiries); and quantified releases according to source. Annual TEQ releases were determined using information received from the questionnaires, together with the default emission factors given in the UNEP toolkit, using the formula: Source strength (PCDD/Fs released per year as g TEQ/yr) = ΣEmission factor $\times$ Activity rate per annum.

Having assessed the sources of pollutants, we considered the means and possible effect of their reduction on TEQ releases. One has to keep in mind that possible releases might have their origins outside the sampling area, notably as regards fuel combustion for electricity generation. The opposite is also true: Potchefstroom's medical waste is not incinerated locally, but in a neighbouring town.

Results and discussion

Questionnaires regarding PCDD/F sources and PCB-containing equipment were distributed to industrial companies identified from a list provided by the Potchefstroom municipal authorities. In all, 23 companies returned the 31 questionnaires. Of the eight that did not, three operated coal-fired boilers (they were two breweries and a hospital). TEQ values for these sources were extrapolated from

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the power generation and heating main source category of the toolkit.[9] Waste from local hospitals is sent to a special-purpose incinerator in Klerksdorp (a neighbouring town); the data are not included in our results. The five other sources comprised two waste-removal companies, a glassworks, a scrap yard and a water purification works. Of these, the waste-removal companies do not incinerate in Potchefstroom and were therefore not considered further. The remaining sources, given their small size or very low POPs generating potential, were deemed not to be significant polluters.

Originally, we intended to quantify PCB releases in the same way as the PCDD/Fs. It was found that industries either did not have equipment that contained PCBs, or were not aware of any. The Potchefstroom municipality takes responsibility for most large electrical transformers. According to the Directorate of Infrastructure, PCB tests were performed on all major sub-stations, with no traces of PCBs found. The relevant documentation could not be traced, however, and PCBs were not considered further.

The estimated TEQ emissions for each main source category, using the default emission factors as given in the toolkit,[9] are presented in Table 1 and Fig. 1. These were determined from the results of the survey questionnaires combined with those from the most recent census,[12] the South African Petroleum Industry Association,[13] and the Heart Foundation of South Africa.[14] The estimated total PCDD/F emissions for Potchefstroom were 0.396 g TEQ/yr, corresponding 0.215 g TEQ/yr to air, 0.181 g TEQ/yr as soil residues, and 0.000006 g TEQ/yr to water media.

The greatest sources of these chemicals were sewage and sewage treatment, waste incineration, mineral products, and power generation and heating. Transport and uncontrolled combustion were also noteworthy contributors to PCDD/F releases. Other potential sources were not recognized and are thus not indicated in our results. The two main sources of PCDD/Fs in industrial centres, but which do not apply to Potchefstroom, are ferrous and non-ferrous metal production, and the manufacture of chemicals and various consumer goods.

Table 1. Estimated PCDD/Fs releases (as g TEQ/yr) in Potchefstroom according to UNEP source categories using default emission factors.

No.	Main source categories and subcategories	Air	Water	Land	Residue
1	**Waste incineration**				
	Medical/Hospital waste	0.05			0.00025
	Animal carcass incineration	0.0338			ND
	Sewage sludge incineration	0.0182			0.00836
	Total	**0.1019**			**0.00861**
2	**Ferrous and non-ferrous metal production**	N/A			
3	**Power generation and heating**				
	Coal-fired boilers	0.005*			0.040*
	Household heating and cooking* with fossil fuels (coal, oil or gas)	ND		ND	ND
	Total	**0.005**			**0.040**
4	**Mineral products**	0.06			ND
	Total	**0.06**			
5	**Transport (General)**				
	Leaded fuel	0.00059*			
	Unleaded fuel	0.0336*			
	Total	**0.0341**			
6	**Uncontrolled combustion processes**				
	Biomass burning	0.000005*			0.000004*
	Waste burning and accidental fires	0.0136*			0.01242*
	Total	**0.0137**			**0.0124**
7	**Production and use of chemicals and consumer goods**	N/A			
8	**Miscellaneous**				
	Drycleaning residues				0.000246
	Tobacco smoking	0.00001228*			
	Total	**0.0000123**			**0.000246**
9	**Disposal/Landfills**				
	Sewage/ sewage treatment		0.000006		0.1205
	Total		**0.000006**		**0.1205**
	Total emission of PCDD/Fs	**0.215**	**0.000006**		0.1809
	Total emission of PCDD/Fs all releases	**0.396**			

*Estimated values. ND, No data. N/A, Not applicable because no sources were identified in Potchefstroom.
Blank spaces indicate that there are no known or suspected releases involved.

Sewage and sewage treatment

The main contributor to the PCDD/Fs load in sewage treatment plants is human waste,[15] household and industrial wastewater, and surface runoff.[16] Dioxin-like chemicals can also be formed by the peroxidase-catalysed oxidation of chlorinated phenols present in the sewage system.[16] The greatest sourcer of POPs in the sewage system of residential areas is wastewater generated by laundering and bathing. The emissions in water were very low compared with sewage sludge (Table 1).

Waste incineration

Only two incinerators were operating during the inventory exercise: a sewage sludge incinerator and one that handles medical waste (operated exclusively on behalf of veterinary activities and research) and animal carcasses. The second-highest TEQ values for Potchefstroom were generated by the incineration of medical waste, followed closely by that of animal carcasses (Table 1), equivalent to 0.111 g TEQ/yr.

Mineral products

The only activity that contributed to this category was brick production, the corresponding release to air was 0.06 g TEQ/yr (Table 1). The kiln used is fuelled by coal, not oil or gas on which the toolkit emission factor is based. Because the Potchefstroom kiln is not fitted with air pollution control (APC),[9] the default emission factor of 10 μg TEQ/ton coal was used.

Power generation and heating

Power generation was the fourth-greatest contributor to PCDD/Fs releases, corresponding to 0.045 g TEQ/yr (Table 1). At the time of compiling the inventory, there were no data concerning household cooking and heating in the study area, and so the polluting effect of this source is uncertain.

Although the electricity used in Potchefstroom is generated elsewhere, the town indirectly contributes to South Africa's PCDD/F burden through its power consumption. During 2005/6, electrical energy equivalent to 375.2 million kWh was used, translating into 0.032 g TEQ/yr (from coal combustion). This value was not added to the town's inventory (Table 1), but should be considered when reviewing the national picture.

Transport

Chlorine in fuels intrinsically leads to the formation of PCDD/Fs during combustion.[17]

Leaded petrol and diesel fuel are the main sources of POPs in the transport sector.[17] The corresponding TEQ value

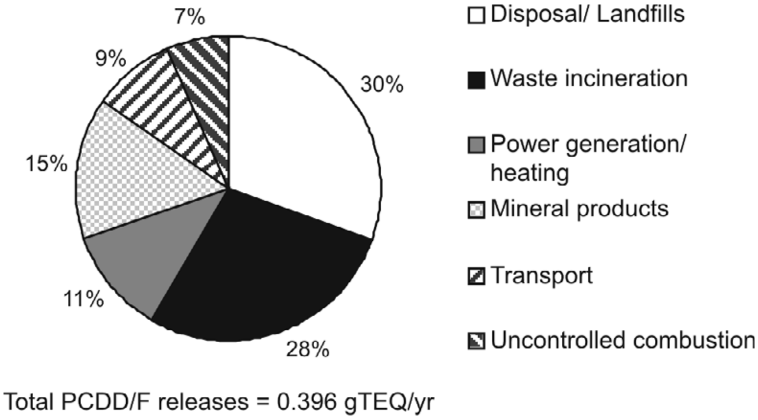

Fig. 1. Estimated total PCDD/F releases according to main source categories, using default emission factors, indicating the percentage contribution of each category to total emissions.

was relatively high at 0.034 g TEG/yr, representing 28.74 million litres of liquid fuels of all kinds sold in 2005. Only approximately 28% of vehicles in North West province ran on unleaded fuel at that time.[13]

Uncontrolled combustion

The tonnage of material burned under uncontrolled conditions is not known, and was estimated from data from the Directorate of Public Safety of Potchefstroom City Council. The only data that could be used were from controlled fires, vehicle fires and biomass burning. The use of domestic coal and other biomass, as an energy source, is unknown. Specific measurements will be required for more accurate calculation of TEQs produced through uncontrolled combustion. The estimated contribution of PCDD/Fs at 0.026 g TEQ/yr (Table 1) may be much less than in reality.

Miscellaneous

Of all the possible 'miscellaneous' categories listed by the toolkit,[9] the only ones that could be quantified were tobacco smoking and drycleaning residues. These were relatively small contributors at 0.00038 g TEQ/yr (Table 1).

Unknown releases from other sources

Potential hotspots for PCDD/Fs as well as PCBs in Potchefstroom include scrapyards and agricultural and pesticide suppliers. These industries are not directly responsible for the release of PCDD/Fs. There could, however, be stockpiles of old pesticides or equipment containing these pollutants.

Effects of emission controls

Figure 2 indicates that with the implementation of air pollution control systems and improved fuel management, the total emission of PCDD/Fs can be decreased by about 40%. The greatest scope for reduced emissions derives from waste incineration, mineral production, and transport. The release of POPs from incinerators is controllable with the correct APC measures. We estimate that they could reduce the pollution load to 0.006 g TEQ/yr, a 95% decrease in emissions. There are several factors that will reduce the formation of these chemicals in incinerators, including proper feed control, optimizing the temperature of incineration (ideally above 850°C), and managing the APC system.[18]

Furthermore, by changing the fuel used in the brick kiln, from coal to oil or gas, emissions will be reduced by approximately 40% (by 0.06 g TEQ/yr to 0.036 g TEQ/yr). Lastly, with the ban on the sale of leaded petrol in January 2006, the emission of PCDD/Fs in this category would have changed dramatically. Lead replacement fuel and unleaded petrol in South Africa (as far as could be established) do not contain halogenated scavengers. For this reason, the same emission factor used in determining the contribution of PCDD/Fs through unleaded petrol was used, because the actual emission factor for lead replacement fuel is not known. The total PCDD/Fs release will decrease by about 94% (from 0.034 g TEQ/yr to 0.002 g TEQ/yr) by prohibiting leaded petrol (Fig. 2).

Comparisons with other inventories

Many published inventories are on a national scale, rather than for a single city or town, so that it is difficult to compare these findings with ours. Indeed, some inventories refer to entire continents or subcontinents.[19] Furthermore, many publications refer to atmospheric emissions only and do not take other environmental compartments (such as soil and water media) into consideration.[20,21] We therefore compared the results for different countries with Potchefstroom's using the percentages that each source category contributed to the respective totals (Table 2). The PCDD/F inventories listed in the table were chosen because they were compiled using comparable inventory methods (not analytical). They also listed values for most of the nine source categories.

The source that contributed the most to the POP releases in Potchefstroom was the disposal/landfill category (30.5%). The corresponding values for New Zealand and Jordan were 88.3% and 16.7%, respectively. Uncontrolled combustion contributed the most to the releases in three of seven countries listed in Table 2: Macedonia (76.5%), Philippines (35.0%) and Lebanon (69.8%) and the second-most in Jordan (10.1%). From this cursory overview, it is clear that three categories—disposal/landfill, waste incineration, and uncontrolled combustion—contribute the most to TEQ releases.

Conclusions

The principal sources of POPs in Potchefstroom were sewage/sewage treatment, incineration, brick production, and power generation and heating. The release of these chemicals can be drastically reduced by the implementation of APC systems, the more efficient use of fuel and the ban on leaded petrol. For the Potchefstroom area, these three changes can reduce releases by some 40%.

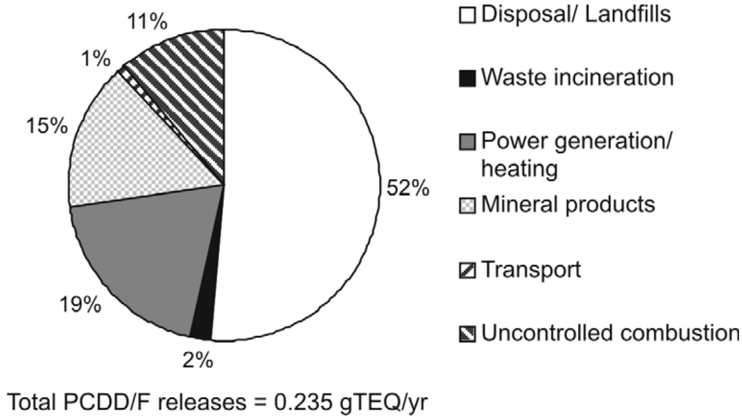

Fig. 2. The introduction of emission controls can reduce the pollution load by about 40%. The chart shows the relative emissions from the various polluting sources as a result of implementing such measures as APC systems, replacing the coal-fired brick-kiln, and banning leaded petrol.

Table 2. Comparative percentage contributions of each source category for Potchefstroom and various countries.

Source	New Zealand (2000)[22]	Macedonia (2004)[23]	Jordan (2003)[25]	Philippines (2003)[25]	Taiwan (2004)[24]	Brunei-Darussalam (2003)[25]	Lebanon (2003)[25]	Potchefstroom
Disposal/Landfill	**88.32***	1.80	**16.71**	8.09		*40.94*	2.30	**30.47**
Waste incineration	4.29	*12.66*	6.04	7.79	11.5	**42.02**	*14.98*	*27.89*
Mineral products	0.21	0.97	1.12	0.49	5.13	4.40	0.71	15.14
Power generation and heating	1.01	2.02	0.70	*29.43*	4.87	1.64	0.45	11.26
Transport	0.11	0.16	1.12	0.02	0.07	4.78	3.18	8.62
Uncontrolled combustion	0.37	**76.51**	*10.08*	**35.02**	–	5.72	**69.79**	6.59
Miscellaneous	0.04	–	0	0.04	0.01	0.49	0	0.09
Ferrous and non-ferrous metal production	1.47	5.88	3.79	1.98	*27.27*	0.01	7.62	–
Chemicals and consumer goods	*4.19***	0.01	0.42	17.15	**51.15**	0	0.97	–
Total PCDD/F emission (gTEQ/yr)	594.2	177.8	71.2	534.2	138.5	1401	77.43	0.40

*Bold indicates source category with highest % contribution in column.
**Italics indicates source category with second-highest % contribution in column.

The greatest obstacle in compiling this inventory was obtaining the necessary information from the public and industries. One of the main reasons for their hesitation in supplying the required information was their lack of knowledge of POPs. There should be more public awareness programmes concerning our nation's responsibilities as a party to the Stockholm Convention. For inventories to be accurately compiled on a national scale, there would have to be funding, support and initiatives from government, on both the local and national level. More research has to be focused on the measurement of PCDD/F releases to supplement the use of default emission factors in inventories. Southern Africa has its own climate and the trends these pollutants show will not necessarily be the same as in developed countries. Releases from non-industrial sources (especially domestic combustion of coal and biomass for heating and cooking) tend to have greater uncertainty due to a lack of both data and precise measurements.

This study showed that inventories have different profiles in different countries and regions, and consequently, there should also be relatively large differences between cities in South Africa, given the varied nature of PCDD/F sources (such as industries) and their distribution over the country.

The TEQs were calculated using default emission factors, since there are no published data on dioxins in Potchefstroom or any other urban areas in South Africa. Furthermore, there are no laboratories currently equipped to test for PCDD/Fs on a routine basis, making compliance with the Stockholm Convention difficult.

Although emission inventories are important as starting points for impact and risk assessment,[17] as well as for identifying the relative contribution of each source, they cannot be directly linked to human exposure.[26] Furthermore, the UNEP toolkit default emission factors (single values only) that were applied,[9] made it difficult to determine a possible range of POPs generated—in general, maximum and minimum values could not be derived. For this reason, mean values were used to report the TEQ of the various sources, to achieve a standard reporting format.

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