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Emissions of Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans (PCDD/PCDFs) in Iran

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Abstract The aim of this study was estimation of PCDD/PCDFs emissions from various sources in Iran. The results indicated total PCDD/PCDFs emissions in Iran in 2010, was 1,957 g TEQ. Of this amount, about 705.8, 0.5, 463.5, 144.1 and 643.2 g TEQ/year was released to air, water, land, products, and in residues, respectively. Open burning processes and metal production are the major contributors to be known environmental sources of PCDD/PCDFs that contribute to about 70% of total PCDD/PCDFs emissions in Iran. The results showed that total PCDD/PCDFs emissions in Iran per inhabitant were about 26.5 g TEQ/million that is high relatively.

Keywords Persistent organic pollutants · Dioxins · Furans · Emission · Iran

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDFs) (called dioxins) are persistent, semivolatile trace organic contaminants, which have been demonstrated to exhibit toxicity to mammals (Zhang et al. 2009). As one of the most toxic pollutants ever known to human, PCDD/PCDFs have attracted much attention all over the world (Ba et al. 2009). PCDD/PCDFs are well-known persistent organic pollutants (POPs) that remain intact in the environment for long periods (Wu et al. 2009). They are formed unintentionally and released as byproducts of human activities such as fuel combustion, waste incineration, chlorine bleaching of pulp and paper, pesticide manufacturing, as well as by natural processes such as forest fires and volcanoes (Cheng and Hub 2010). The largest release of these chemicals today is open burning of household waste, municipal waste, medical waste, landfill fires, and agricultural and forest fires (Dyke et al. 1997).

Although human exposure to PCDD/PCDFs can occur by various routes, food is the primary source. A few studies have reported that 90%–95% of the exposure is from food ingestion (Llobet et al. 2003). Exposure to PCDD/PCDFs have been associated with a wide range of adverse health effects in laboratory animals and humans such as: soft tissue, sarcomas, lymphomas, skin lesions (chloracne), stomach cancer, biochemical liver-test abnormalities, elevated blood lipids, fatal injury, immune system and neurological effects (Kulkarni et al. 2008).

Realizing the serious health risks and particularly the persistence of these compounds, the global community took action to develop a legal international treaty to prevent the production, use and trade and proper management of these substances. This international campaign led to the creation of the Stockholm Convention on Persistent Organic Pollutants in 2000. The Islamic Republic of Iran has signed the treaty and the final stages of ratification are followed in the Parliament.

Since the PCDD/PCDFs analysis and measurement are expensive, there is no accurate estimate of PCDD/PCDFs emissions in developing countries. To help countries as they identify emission sources and estimate releases of PCDD/PCDFs, United Nation Environmental Programme (UNEP) has developed a Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. This toolkit is designed as a simple and standardized method and accompanying database to enable assembling the consistent national and regional PCDD/PCDFs

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inventories. The basic aim of the UNEP toolkit is to enable an estimate of average annual release in each vector (air, water, and land, in products and residues) for each process identified (UNEP 2005). The toolkit is organized in ten categories regarding different activities such as waste incineration, ferrous and nonferrous metal production, power generation and heating, production of mineral products, transportation, uncontrolled combustion, production and use of chemicals and consumer goods, miscellaneous activities, disposal and hot spots.

The estimate of PCDD/PCDFs can be calculated by the following basic equation:

$$\text{Source Strength (PCDD/PCDFs emissions per year)} = \text{Emission Factor} \times \text{Activity Rate} \quad (1)$$

The PCDD/PCDFs emission per year is calculated and presented in grams of toxic equivalents (TEQ) per year.

In most countries, several studies have identified and estimated dioxin and furan emissions, but in Iran, there was not any data about total dioxin and furan emissions. Therefore, this study has been done to estimate the PCDD/PCDFs total emission in Iran according to the UNEP standardized procedures, and to determine the share of their sources and hotspots in Iran.

Materials and Methods

The major used method in the present study was based on recommended five-step approach to establish a national PCDD/PCDFs release inventory using UNEP Toolkit.

In the present study, the first step in developing a standardized PCDD/PCDFs source inventory for Iran was identification of main source categories and the primary release routes for each category. A coarse screening matrix was applied to identify the present main PCDD/PCDFs source categories in Iran (Table 1).

The second step details these main source categories further into subcategories checked to identify individual activities, which potentially release PCDD/PCDFs. In this step, processes or subcategories within each main source category identified. For comparability, each of the nine main source categories in Iran had been divided into a series of subcategories as below:

- Waste Incineration: Hazardous waste incineration, Medical waste incineration and Destruction of animal carcasses.
- Ferrous and Non-Ferrous Metal Production: Iron ore sintering, Coke, Iron and steel and foundries, Galvanized sheets, Copper, Aluminum, Lead, Zinc, Brass and bronze.
- Heat and Power Generation: Fossil fuel power plants and Domestic heating.
- Production of Mineral Products: Cement, Lime, Brick, Glass, Ceramics and Asphalt mixing.
- Transportation: 4-Stroke engines, 2-Stroke engines, Diesel engines and Heavy oil fired engines.
- Open Burning Processes: Forest fires, Grassland and moor fires, Agricultural residue burning, Accidental fires in houses and factories, Uncontrolled domestic waste burning, Accidental fires in vehicles and Open burning of wood (construction/demolition).
- Production and Use of Chemicals and Consumer Goods: Pulp and paper production, Chlorinated Pesticides, PVC, Petroleum industry, Textile plants and Leather plants.
- Miscellaneous: Treated wood, Waste fuels used as fuel and Cigarette.
- Disposal: Landfill leachate, Sewage treatment and Composting.

In the third step, detailed information on the processes was gathered and processed into similar groups by applying the standard questionnaire were classified. To achieve the

Table 1 Main source categories and the main release routes in Iran

No.	Main source categories	Potential release route				
		Air	Water	Land	Product	Residue
1	Waste incineration	×				×
2	Ferrous and non-ferrous metal production	×				×
3	Power generation and heating	×		×		×
4	Production of mineral products	×				×
5	Transportation	×				×
6	Uncontrolled combustion	×	×	×		×
7	Production and use of chemicals and consumer goods	×	×		×	×
8	Miscellaneous activities	×	×	×	×	×
9	Disposal	×	×	×		×

aims of this study, necessary data were gathered by referring to the related organizations and the UNEP prepared questionnaires were filled. Size, scale and process information, were relevant to the assessment. Within one subcategory to produce the same product, the emissions of PCDD/PCDFs can vary considerably depending on technology, performance, etc. and often only, an estimate is possible. Therefore, to estimate the emissions of PCDD/PCDFs correctly, were collected entire information about each subcategory.

In the fourth step, emissions were calculated based on information obtained in the previous steps via Eq. 1. The last step was then the compilation of the standardized PCDD/PCDFs inventory using the results generated in steps 1 through 4. The annual emissions of all individual subcategories were added to give the emissions across all five potential vectors for the nine main source categories. Finally, the emissions of all nine main source categories were added up, and the national inventory was calculated, which represents the total estimated release from all identified and quantified sources in Iran.

Results and Discussions

The amounts of PCDD/PCDFs being released from all categories and their related subcategories are presented in Table 2. Results showed that an estimated 1,957.3 g TEQ of PCDD/PCDFs was released into the environments of Iran in 2010.

As presented in Table 2, uncontrolled domestic waste burning is the largest source of PCDD/PCDFs emission in Iran, which is the result of present many rural areas in Iran that burn their wastes. In many rural areas of Iran, there are not proper waste management methods and people in these regions usually burn their wastes. Copper, iron and steel are also the next major sources of PCDD/PCDFs emission in Iran.

The Contribution of individual sources is presented in Fig. 1.

Figure 1 shows that open burning processes and metal production are the major contributors to be known environmental sources of PCDD/PCDFs that contribute to about 70% of total PCDD/PCDFs emissions in Iran. The next important sources are disposal, mineral products, chemical goods, waste incineration, power generation, transportation, and miscellaneous, respectively.

Figure 2 compares the PCDD/PCDFs released from all the media. It showed that release of these compounds to air is the predominant medium contributing to 36% of the total (38%, 27.6%, and 23.5%, respectively from open burning processes, production of mineral products, and ferrous and non-ferrous metal production) followed by residue (32.8%)

Table 2 Total PCDD/PCDFs emission in Iran from main source categories in 2010

Main source categories	Subcategories	Annual releases (g TEQ/year)
Waste incineration	Hazardous waste incineration	0.217
	Medical waste incineration	44
	Destruction of animal carcasses	2.19
	Total	46.4
Ferrous and non-ferrous metal production	Iron ore sintering	127.3
	Coke	0.208
	Iron and steel and foundries	192
	Galvanized sheets	0.012
	Copper	268.6
	Aluminum	47.04
	Lead	0.43
	Zinc	0.041
	Brass and bronze	0.065
	Total	635.7
Heat and power generation	Fossil fuel power plants	13.23
	Domestic heating	5.28
	Total	18.5
Production of mineral products	Cement	182.91
	Lime	1.36
	Brick	9.90
	Glass	0.28
	Ceramics	0.18
	Asphalt mixing	1.56
	Total	196.2
Transportation	4-Stroke engines	1.72
	Diesel engines	1.5
	Heavy oil fired engines	3.06
	Total	6.3
Open burning processes	Forest fires	1.45
	Grassland and moor fires	5.4
	Agricultural residue burning	24
	Accidental fires in houses and factories	29.2
	Uncontrolled domestic waste burning	656.34
	Accidental fires in vehicles	0.085
	Open burning of wood	16.41
	Total	732.8

Table 2 continued

Main source categories	Subcategories	Annual releases (g TEQ/year)
Production of chemicals and consumer goods	Pulp and paper production	22.82
	Chlorinated pesticides	1.2
	PVC	0.001
	Petroleum refineries	4.5
	Textile plants	22
	Leather plants	11.61
	Total	62.1
Miscellaneous	Treated wood, waste fuels	2.12
	Cigarette	0.006
	Total	2.2
Disposal	Landfill leachate	5.2
	Sewage treatment	142.5
	Composting	109.25
	Total	257
Total		1,957.3

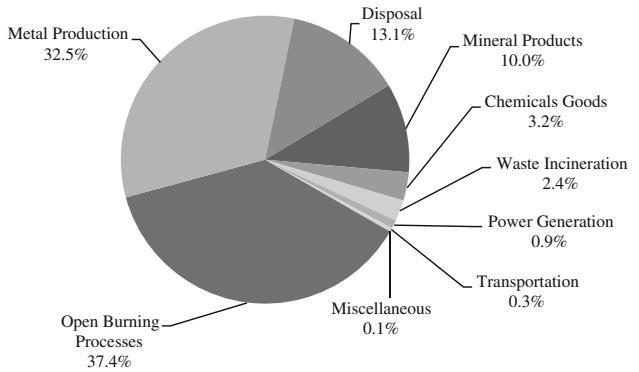

Fig. 1 Contribution of the major sources to PCDD/PCDFs emission in Iran

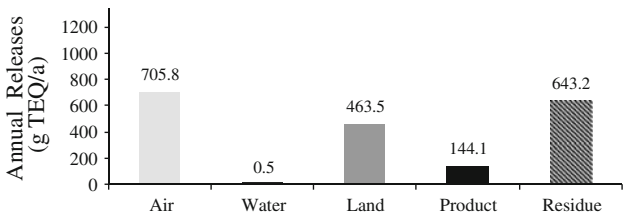

Fig. 2 Comparison of PCDD/PCDFs releases from all media (categories 1–9)

(73% and 23% from ferrous and non-ferrous metal production and disposal, respectively, and the other sources contribute about 4%), land (23.68%) (Only from open burning processes), product (6.36%) (75% and 25% from disposal and production of chemicals and consumer Goods,

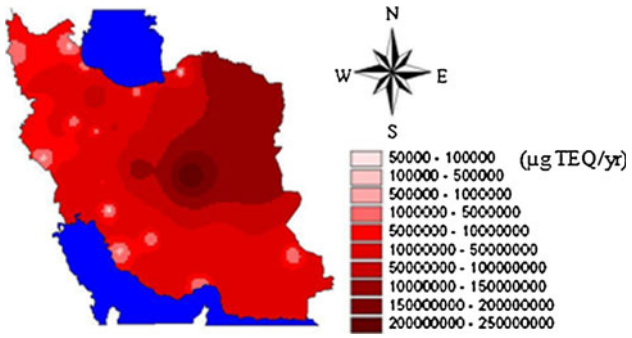

Fig. 3 PCDD/PCDFs releases in Iran

Table 3 Comparison of PCDD/PCDFs emission in Iran in 2010 with other countries in 2004 (Pulles et al. 2004)

Region	PCDD/PCDFs emission (g TEQ/year)	Population (millions)	Relative emission (g TEQ/million)
Iran	1,957.3	74	26.45
France	1,100	58.9	18.7
Italy	1,100	57.7	19.1
United Kingdom	930	58.7	15.8
Germany	840	82.2	10.2
Belgium	490	10.2	48.0
Spain	330	40.5	8.1
Switzerland	180	7.2	25.0
Portugal	130	10.0	13.0
Austria	120	8.1	14.8
Greece	120	10.6	11.3
Netherlands	120	15.9	7.5
Sweden	90	8.9	10.1
Finland	70	5.1	13.7
Jordan	53.6	5.5	10
Denmark	50	5.3	9.4
Luxemburg	50	0.4	125.0
Norway	40	4.5	8.9
Lebanon	38.5	3	13
Ireland	35	3.8	9.2
Haifa district	0.9	0.5	1.8

respectively), and water (0.02%) (Only from disposal). This order of arrangement is probably because the emission factors for air releases are the most complete as compare to the other media.

Figure 3 shows the distribution of PCDD/PCDFs releases in Iran. The most important provinces in these regards are the east and northeast provinces that are due to industrialization and improper wastes management.

In Table 3, total PCDD/PCDFs emission in Iran was compared with those in the other countries.

The table clearly shows that PCDD/PCDFs emissions in Iran are high relatively per inhabitant basis. This is mainly due to uncontrolled domestic waste burning in the rural areas and metal production industries.

Conclusion

The main objective of this study was estimation of PCDD/PCDFs emissions from various sources in Iran. In the present study, UNEP Toolkit was used to estimation of PCDD/PCDFs emission from different sources in Iran. The Toolkit is very useful for the estimation release of PCDD/PCDFs into the environment. The obtained results showed that an estimated 1,957.3 g TEQ of PCDD/PCDFs was released into the environments in Iran in 2010. The results also showed that total PCDD/PCDFs emissions in Iran per inhabitant were about 26.5 g TEQ/million that is high relatively.

The main sources of PCDD/PCDFs releases in Iran are open burning processes and metal production plants. Both sources have contributed to 70% of total release into the environment. Uncontrolled domestic waste burning is the largest source of PCDD/PCDFs emissions in Iran. The main release route of PCDD/PCDFs emissions in Iran and many of the other countries is the air (Wu et al. 2009). Unfortunately, one of the main disposal methods of household wastes and residues of agricultural products in the rural area in Iran is open burning. Therefore, proper waste management in the rural area and improve the combustion processes and systems of copper and iron and steel plants could reduce the PCDD/PCDFs emissions significantly.

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