Emission Inventory of Air Toxic Pollutants from Household Solid Waste Open Burning in Vietnam

Lai Nguyen Huy*, Ekbordin Winijikul, Nguyen Thi Kim Oanh

Environmental Engineering and Management

School of Environment, Resources and Development, Asian Institute of Technology, Thailand

Email: lainguyenhuy@gmail.com

Introduction

Generation of household solid waste (HSW) is an evitable environmental concern in Vietnam, especially in suburban areas. As a way to control huge amount of HSW, uncontrolled open burning at sources and at disposal sites is commonly observed in Vietnam (Ngan, 2018; Luong et al., 2013). The HSW generation per capita in Vietnam in kg/cap/yr were 1.33 and 0.48 in urban and rural areas, respectively (INDOCHINE, 2018).

Burning of HSW releases various kinds of air toxics, including acidifying gases and ground-level ozone precursors (SO_2, NO_x, NH_3, CO, NMVOCs), particulate mater (PM_{10}, $PM_{2.5}$) and its associated carbonaceous components (BC, OC), greenhouse gases (CO_2, CH_4, N_2O) and other harmful compounds (i.e. benzene, total polychlorinated dibenzo-p-dioxins (PCDD), total polychlorinated dibenzo furans (PDCF), total polychlorinated biphenyls (PCB).

This study aimed at developing an emission inventory of above-mentioned air pollutants released from open burning of MHSW in Vietnam for base year 2015. To our best knowledge, it is the first time this study has been conducted in Vietnam, which would bring in important findings for air quality management of the country.

Methodology

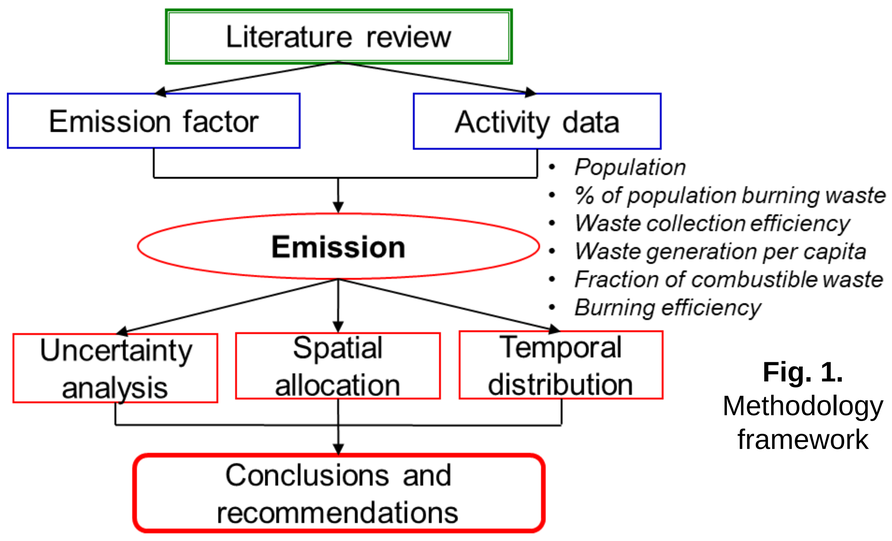

Fig. 1. Methodology framework

(1) $$Em_i = M_s \times EF_i$$

Em_i : emission of specie *i* (g/year);
EF_i : emission factor of specie *i* (g/kg of dry matter burned);
M_s : amount of HSW burned (kg/year).

HSWOB at sources

(2) $$M_s = P_c \times P_{frac} \times HSW_{GR} \times \delta \times \eta \times 365$$

M_s : amount of open-burned MSW (kg/year),
P_c : population,
P_{frac} : fraction of population burning waste,
HSW_{GR} : per capita HSW generation factor (kg waste/capita/day),
δ : fraction of combustible HSW,
η : burning/oxidation efficiency.

HSWOB at disposal sites

(3) $$M_s = P_c \times HSW_{GR} \times \varepsilon \times \lambda \times \delta \times \eta \times 365$$

M_s : amount of open-burned MSW (kg/year),
P_c : population,
P_{frac} : fraction of population burning waste,
HSW_{GR} : per capita HSW generation factor (kg waste/capita/day),
ε : HSW collection efficiency,
λ : fraction of SW burned relative to total amount of SW disposed at disposal site,
δ : fraction of combustible HSW,
η : burning/oxidation efficiency.

Table 1: Summary of calculated variables used in this study

Variable	Area	Value (Low-Best-High)	References/Remarks
Population (P_c), capita		-	Provincial Statistical Yearbook in 2015
Fraction of population burning waste (P_{frac})	Urban	0.15 – 0.16 – 0.22	Uncollected waste rate from Ngan (2018)
	Rural	0.45 – 0.5 – 0.6	Uncollected waste rate from INDOCHINE (2018)
Per capita HSW generation factor (HSW_{GR}), kg waste/capita/day	Urban	1 – 1.3 – 2	Damanhuri et al. (2009), MONRE (2004), Ngan (2018)
	Rural	0.3 – 0.4 – 0.43	Bensusan et al. (2016), MONRE (2004)
Fraction of combustible HSW (δ)	Urban	0.09 – 0.268 – 0.57	Damanhuri et al. (2009), Das et al. (2018), Schneider et al. (2017)
	Rural	0.57 – 0.654 – 0.716	Bensusan et al. (2016), Das et al. (2018)
Burning/oxidation efficiency (η)	Urban/ Rural	0.58	IPCC (2006)
HSW collection efficiency (ε)	Urban	0.71 – 0.84 – 0.85	MONRE (2004), Ngan (2018)
	Rural	0.45 – 0.5 – 0.6	INDOCHINE (2018)
Fraction of SW burned relative to total amount of SW disposed at disposal site (λ)	Urban/ Rural	0.4 – 0.45 – 0.5	Luong et al. (2013)

Uncertainty analysis was done by error propagation equations by IPCC (2006). Two rules:

Rule 1: uncertain quantities are to be combined by addition

$$U_{total} = \frac{\sqrt{(U_1 \times X_1)^2 + (U_2 \times X_2)^2 + ... + (U_n \times X_n)^2}}{(X_1 + X_2 + ... + X_n)} \quad (4)$$

U_{total} : uncertainty in the sum of the quantities;
X_n : uncertainty quantities;
U_n : % of uncertainties.

Rule 2: uncertain quantities are to be combined by multiplication

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2} \quad (5)$$

U_{total} : uncertainty in the product of quantities;
U_n : % uncertainties.

Key findings

Table 2: Annual emissions air pollutants from HSW open burning (HSWOB) in Vietnam, 2015 (t/yr)

Air pollutants	HSWOB at sources	HSWOB at disposal sites	Total best estimate (t/yr)	Total emission range (t/yr)
Acidifying gases and ground-level O_3 precursors				
SO_2	894	8	902	481 – 1560
NO_x	5364	49	5413	2883 – 9361
CO	75,091	683	75,774	40,369 – 131,050
NMVOC	26,818	244	27,062	14,417 – 46,804
NH_3	1681	15	1696	903 – 2933
PM and carbonaceous components				
PM_{10}	53,636	488	54,124	28,835 – 93,607
$PM_{2.5}$	17,521	159	17,680	9419 – 30,578
BC	9833	90	9923	5286 – 17,161
OC	9833	90	9923	5286 – 17,161
Major GHGs				
CO_2	2,597,780	23,645	2,621,425	1,396,566 – 4,533,707
CH_4	11,621	106	11,727	6248 – 20,282
N_2O	268	2.4	270.4	144 – 468
Other air toxics				
Chlorobenzenes	0.68	0.01	0.69	0.37 – 1.19
Benzene	2011	18	2029	1081 – 3510
Acetone	1525	14	1539	820 – 2662
Styrene	1200	11	1211	645 – 2094
Phenol	227	2.1	229.1	122 – 396
Dichlorobenzenes	0.259	0.002	0.261	0.14 – 0.45
Trichlorobenzenes	0.179	0.0016	0.1806	0.10 – 0.31
Tetrachlorobenzenes	0.120	0.001	0.121	0.06 – 0.21
Pentachlorobenzenes	0.086	0.001	0.087	0.05 – 0.15
Hexachlorobenzenes	0.0358	0.0003	0.0361	0.02 – 0.06
Total PAHs	107	1.0	108	58 – 187
Acenaphthylene	17.88	0.16	18.04	9.6 – 31.2
Naphthalene	28.61	0.26	28.87	15.38 – 49.92
Phenanthrene	11.80	0.11	11.91	6.34 – 20.59
PCDD	0.062	0.001	0.063	0.03 – 0.11
PCDF	0.0098	0.0001	0.0099	0.01 – 0.02
PCB	4.65	0.04	4.69	2.50 – 8.11
HCl	461	4.2	465.2	248 – 805
HCN	760	7.0	767	408 – 1326

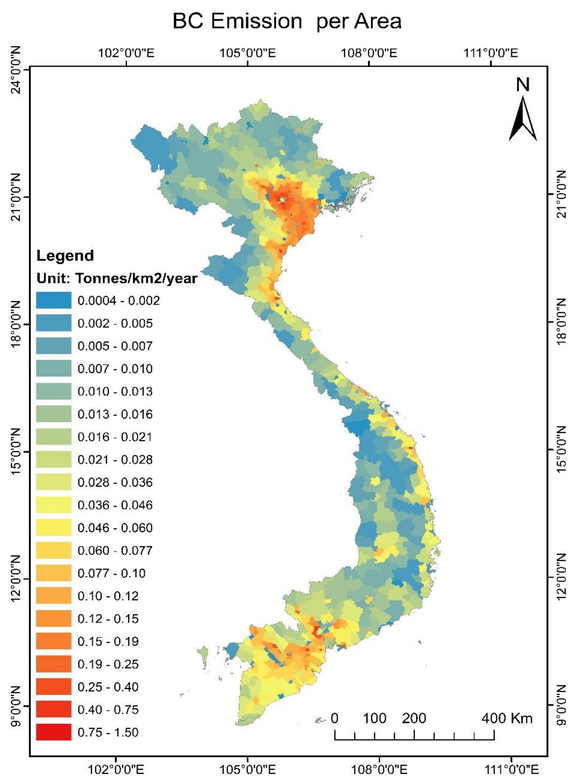

Fig.2. District spatial allocation of BC emission per area in tonnes/km2/year in Vietnam, 2015

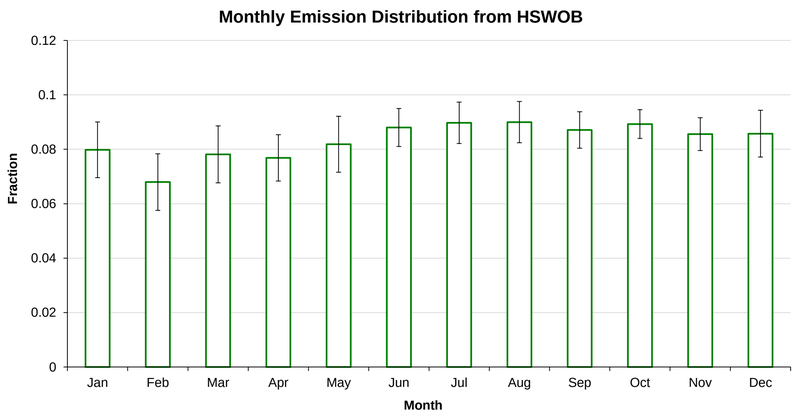

Fig.3. Monthly emission distribution from HSWOB in Vietnam

- The uncertainty of national emissions from HSWOB at sources and at disposal sites: **6.4%** and **4.8%**, respectively.
- The combined uncertainty for both HSWOB at sources and at disposal sites: **6.4%**.

Conclusions

- Total emissions: SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, $PM_{2.5}$, BC, OC, CO_2, CH_4, N_2O and other air toxics: 902, 5413, 75,774, 27,062, 1696, 54,124, 17,680, 9923, 9923, 2,621,425, 11,727, 270.4, and 6414 tonnes/year,
- 99% of total emissions from HSWOB from at sources,
- High emissions found in high-density rural population,
- No significant differences in monthly emissions from HSWOB,
- Uncertainty of national emissions at sources and at disposal sites: 6.4% and 4.8%, respectively; combined uncertainty: 6.4%.

References

- INDOCHINE. (2018). Vietnam's solid waste sector outlook and engineering opportunities.
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