EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 43 (2021): 8-15
Journal homepage: https://eqa.unibo.it/

published by

Characterization of Halogen (Cl, Br, I) emissions from cooking fuels in Nigerian households using energy-dispersive X-ray Fluorescence Spectrometry

Francis Olawale Abulude[1*], Mohammed Mohammed Ndamitso[2], Akinyinka Akinnusotu[3], Samuel Dare Oluwagbayide[4]

1 Science and Education Development Institute, Akure, Ondo State, Nigeria
2 Department of Chemistry, Federal University of Technology, Minna, Niger State, Nigeria
3 Department of Science Laboratory, Technology,
Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria
4 Department of Agricultural and Bio-Environmental Engineering, the Federal Polytechnic. Ilaro, Ogun State, Nigeria

Corresponding author e-mail: walefut@gmail.com

ARTICLE INFO
Received 25/9/2020; received in revised form 6/2/2021; accepted 16/2/2021.
DOI: 10.6092/issn.2281-4485/11572

Abstract
Studies have shown that most of the fuels used in developing countries were generally from wood biomass. Residential emission from traditional biomass cookstoves is a major source of indoor and outdoor air pollution. However, the exact quantification of the contribution of biomass cookstove emissions to outdoor air is still lacking. To address this gap, we designed a study to estimate the halogens present indoors, from cookstove smoke using biomass fuel. A non-destructive analysis method for total bromine (Br), chlorine (Cl), and iodine (I) contents in $PM_{2.5}$ were established using an energy-dispersive X-ray fluorescence (EDXRF) spectrometry. The results (ng m^{-3}) were Not Detectable (ND) to 0.39, 1.94 - 181, and ND - 233 for Br, Cl, and I respectively. Results depicted that fuels from bamboo, palm, maize shafts, and Spondias mombin produced the highest emissions of halogens.

Keywords
bromine, halogens, iodine, Tectona grandis, Gliricidia sepium, biomass, polarizing EDXRF

Introduction

There has been increasing evidence, that halogens (Cl, Br and I) play important roles in determining the composition of the troposphere (Sherwen *et al.*, 2017), they affect CH_4, O_3, and particles, all of which, by direct and indirect radiative effects, are active climate forcing agents. The high reactivity of atomic halogen radicals (e.g., Cl, Br, I) and halogen oxides are responsible for this effect. (Allen *et al.*, 2009; Fernandez *et al.*, 2014; Simpson *et al.*, 2015; Hossaini *et al.*, 2016). Halogens have been confirmed to influence the formation of secondary air pollutants (Li *et al.*, 2019). Interactions between the halogens and HOx, NOx, and volatile organic compounds (VOC) species leads to halogens having a pervasive influence throughout the tropospheric chemistry system (Schmidt *et al.*, 2016, Sherwen *et al.*, 2016). The chemistry of Br and I is

DOI: 10.6092/issn.2281-4485/11572

thought to lead to reductions in O_3 and OH mixing ratios globally (Parrella *et al.*, 2012, Saiz-Lopez et al., 2014, Schmidt *et al.*, 2016, Sherwen *et al.*, 2016) whereas the chemistry of Cl is thought to lead to both increases in O_3 due to more rapid oxidation of VOCs (Simon *et al.*, 2009, Burkholder *et al.*, 2015) and decreases due to halogen nitrate hydrolysis reducing O_3 production (via decreasing NOx) (Schmidt *et al.*, 2016).

Air pollution in the atmosphere is due to natural and anthropogenic activities such as fossil fuel combustion, i.e., natural gas, coal, and oil, to power industrial processes and motor vehicles (Beguma *et al.*, 2009). CO_2, CO, NOx, SO_2, and aerosols get into the atmosphere through the combustion of materials, such as traditional biomass fuels which include, wood, cow dung, and crop wastes. Residents of the particular areas of biomass combustion are prone daily to harmful emissions and other health risks. In the affected areas of pollution, those individuals exposed to enhanced concentrations of pollutants are women and their children, who spend most of their time in the kitchen cooking (Smith *et al.*, 2004).

Acute respiratory infection, lung cancer, and chronic obstructive pulmonary disease were linked to open fires used in the kitchens as household fuels in developing countries (Smith *et al.*, 2000; Chowdhury *et al.*, 2015). Generally, in these countries, fuels such as biomass, coal, dried woods, plastics, animal dung, paper, crop residues, and dried leaves are the common ones used. High morbidity and mortality rates were recorded in young children in developing countries, the symptoms of these were acute respiratory infections and primarily pneumonia. According to WHO (2010), indoor air pollution is the cause of death of over 1.5 million young children and moms who stayed most times at home and in the kitchen.

There are many types of household stoves for cooking and heating across the world. These stoves emissions are known to be hazardous to human health and impact climate, but in practice emissions measurements largely focus on a subset of these; those that are important markers for health endpoints (respirable particles, carbon monoxide, SO_2), and those that are important to estimate climate impacts (CO_2, CO, CH_4, non-methane hydrocarbons, N_2O, and the mixtures of elemental (black) and organic carbon in the fine particulate matter) (WHO 2016).

During recent years, there have been many studies conducted to evaluate indoor air pollution. These studies were based on the kitchen, living rooms, and other parts of the buildings (Lim *et al.*, 2012; Smith *et al.*, 2014; WHO, 2016; Khan *et al.*, 2017; (Ubuoh and Nwajiobi, 2018). Many studies showed that most of the fuels used in developing countries were generally from wood biomass. The biomass combustion consists of emissions due to the types and quality of fuel used, combustion technologies, and operating conditions (Tissari *et al.*, 2008). In Chandrasekaran *et al.*, (2012) report, it was stated that the quality and chemical composition depends upon the nature of the plant species, for example, the ash content varies with inorganic species present in the biomass, which ranges from 0.5 to 3% dry weight (dw), carbon (from 45 to 50% of the mass), oxygen (about 40–50%), hydrogen (about 6%), nitrogen (less than 1%), and elements such as Ca, K, Na, Mg, Mn, Fe, Al, Cd, Cr, Cu, Ni, Zn, As, Hg, and Pb. Iodine (I) is known to be useful in human nutrition for the synthesis of thyroid hormones, but its deficiency results in goiter. It was reported that over two billion people over the world were linked to the risk of I problem due to little intake (WHO 2004; de Benoist *et al.*, 2008). The action and effect of I in the environment should be elucidated, due to its significant effect on agricultural production and human health (Takeda *et al.*, 2011). According to Kabata-Pendias and Mukherjee (2007), Br (as methyl bromide and ethylene dibromide) is used in as fungicides, herbicides, and insecticides in agricultural productions. Br in excess in the human body is harmful. McLeod *et al.* (2015), reported the usefulness of the halides in solar cells. The usefulness was enumerated as light-absorbing materials and improves device performance. Also reported was that the halides' ratios are useful in tracing groundwater salinity (Alcalá, 2019).

Previous research dealt purposely on the Cl content on air quality over large spatial scales (Li *et al.*, 2019). Little or no attention has been paid to the halogen contents on air quality due to household cooking energy. This paper aimed at assessing the concentrations of Br, I, and Cl in particulate matter ($PM_{2.5}$ µm) obtained from different fuels firewood, and the gas used by different homes in Akure. The report in this study is an overview of the results of the EDXRF analysis.

Materials and methods

The study location, Akure, capital of Ondo State, lies in southwest Nigeria. It has an area of 991 km^2 and a population of approximately 485,000. It has an

DOI: 10.6092/issn.2281-4485/11572

annual average temperature of 29 °C, wind W at 8 km/h, 73% humidity. The measurement site was at Oba Ile (7°15'56.21" N–5°15'18.16" E), in the typical residential urban area (Figure 1). The measurement period was from July 24th to August 1st, 2018. During the period, a three-stone (same height) cooking fire stove using seven different fuels: teak (*Tectona grandis* L.f.), bamboo (*Bambusa valgaris,* Schrad), mango (*Mangifera indica* L.), gliricidia (*Gliricidia sepium* (Jacq.) Steud.), palm kernel seeds (*Elaeis guineensis* Jacq.), hog plum (*Spondias mombin* L.), maize cob (*Zea mays* L.) and gas (LPG) were used for cooking of *Vigna unguiculata* (L.) in two different kitchens (Figure 2). The fuels used during the cooking periods were obtained within the vicinity of the study area and sun-dried until they were devoid of moisture. The cooking time for each period was one hour thirty minutes.

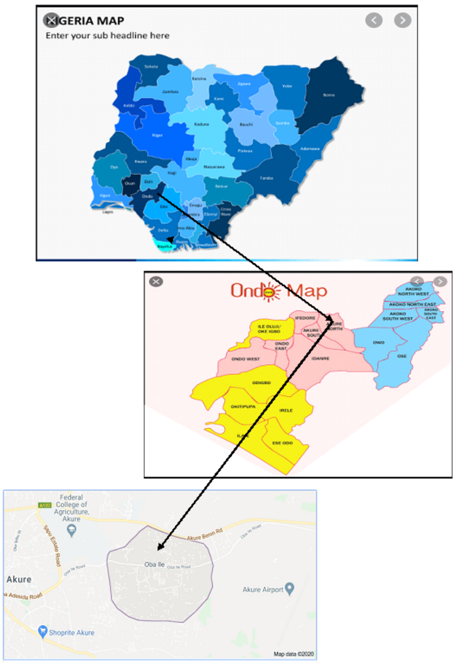

Figure 1. *The map of Nigeria, State, and the location of sampling Oba Ile (7°15'56.21N–5°15'18.16"E).*

Figure 2. *A typical household kitchen used in the study area.*

DOI: 10.6092/issn.2281-4485/11572

During sampling, one type of filter (nylon) was used (Table 1). All the samples were collected using Partisol™2025 samplers (Thermo Scientific, USA) placed on a stand. The filter sample was exposed for 5h. The flow rate was 16.7 L min^{-1}. Flow rates were recorded before and after sampling. The filters were pre- and post-weighed using an XP2U Microbalance (Mettler Toledo, Columbus, OH). After sampling, the filter were placed in Petri dishes, and sealed in plastic bags until returned to the United States, and then post-weighed. X-ray fluorescence measurement was performed on an EDXRF spectrometer (Takeda *et al.*, 2011).

The data obtained in the study was compiled and analyzed using SPSS 12.0 software.

Table 1. *The information about the kitchen used in the study*

Date	Code	Filter	Time	Types of fuel used	Status*
24th July, 2019	#3	Nylon	5 h	Teak (*Tectona grandis.*)	P
24th July, 2019	#15	Nylon	5 h	Teak (*Tectona grandis*)	P
25th July, 2019	#2	Nylon	5 h	Bamboo (Bambuseae)	P
25th July, 2019	#8	Nylon	5 h	Bamboo (Bambuseae)	P
26th July, 2019	#1	Nylon	5 h	Mango (*Mangifera indica*)	P
26th July, 2019	#7	Nylon	5 h	Mango (*Mangifera indica*)	P
27th July, 2019	#14	Nylon	5 h	Gliricidia (*Gliricidia sepium*)	P
27th July, 2019	#16	Nylon	5 h	Gliricidia (*Gliricidia sepium*)	P
28th July, 2019	#5	Nylon	5 h	Palm Kernel (*Elaeis guineensis*)	P
28th July, 2019	#13	Nylon	5 h	Palm Kernel (*Elaeis guineensis*)	P
29th July, 2019	#17	Nylon	5 h	Hog plum *(Spondia mombin)*	P
29th July, 2019	#12	Nylon	5 h	Hog plum *(Spondia mombi)n*	P
30th July, 2019	#18	Nylon	5 h	Maize cob (*Zea mays*)	P
30th July, 2019	#10	Nylon	5 h	Maize cob (*Zea mays*)	P
31st July, 2019	#9	Nylon	5 h	Gas	M
31st July, 2019	#6	Nylon	5 h	Gas	M

*Medium (M) – One door with one window; Poor (P) – One door with no window

Results and Discussion

Concentrations of Br, Cl, and I in the samples measured by the EDXRF are shown in Table 2. The concentrations of Br ranged from ND to 0.39 ng m^{-3}, Cl ranged between ND to 181 ng m^{-3}, and those of I ranged from ND to 233 ng m^{-3}. Most of the Br, Cl, and I contents reported previously for particulate matter are within the concentration ranges in this study (Bettinelli *et al.*, 2002; Flores *et al.*, 2008; Peng *et al.*, 2011), but lower than those reported by Eleanne *et al.* (2013).

DOI: 10.6092/issn.2281-4485/11572

Table 2. *Concentrations of Br, Cl, and I in the samples (ng m^{-3})*

Fuels	Chlorine	Bromine	Iodine
Teak (*Tectona grandis*)	7.94 - 11.4	ND - 0.06	ND - 182
Bamboo (Bambuseae)	67 - 138	ND - 0.23	ND
Mango (*Mangifera indica*)	47 - 78	ND	ND
Gliricidia (*Gliricidia sepium*)	47 - 97	ND	ND - 233
Palm *(Elaeis guineensis)*	67 - 138	0.11 - 0.20	ND
Spondias (*Spondias mombin)*	ND - 148	ND - 0.24	ND – 233
Maize (*Zea mays*)	ND - 181	ND - 0.39	ND
Gas	1.94	ND	ND

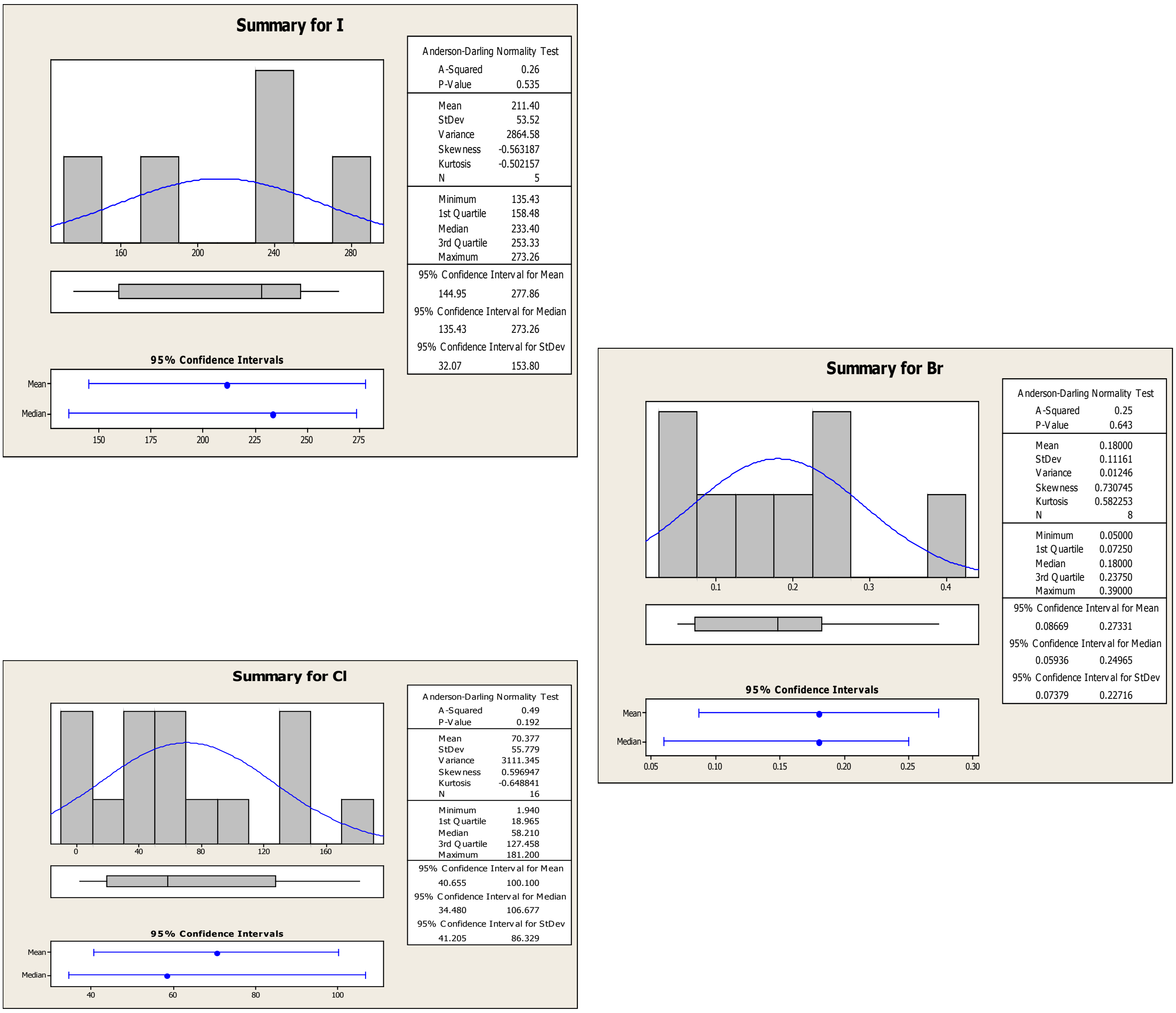

Figure 3. *Graphical summary results of the halogens in the samples.*

DOI: 10.6092/issn.2281-4485/11572

The information about the kitchen characteristics, cookstove type, fuel composition, and other attributes related to cooking activity in the households used for this study has been presented in Table 1 with ventilation status classified according to Adhikari *et al.* (2020). From this study, it was revealed that most of the households in areas chosen are poorly ventilated. These tallies with the results of a study undertaken by Akagi *et al.* (2011) in Nepal, where it was observed that over 70% and 85% of households in land and rural locations of Nepal are poorly ventilated.

Br, I, and Cl concentrations in the PM obtained from the kitchens (Figure 3) exhibited great variations and were much higher than those in the ambient urban atmosphere. The highest mean Cl concentration, 181 ng m^{-3}, was observed in the PM from household cooking with maize straw, followed by cooking fuel with *Spondias mombin* (148 ng m^{-3}).

In contrast, the PM obtained from the cooking with gas supply had the lowest PM_{10} Cl concentration (1.94 ng m^{-3}).

The Cl concentration ranged from 1.94 – 181 ng m^{-3} with a mean value of 70. The variability of Cl concentrations of smoke among the households can be attributed to factors such as types of kitchen structures/size/volume, cooking style, exfiltration rate, air exchange rate between inside and outside the kitchen, combustion temperature, moisture content of the fuel, the carbon content of the fuel, and prevailing metrological conditions (Begum *et al.*, 2009; Soneja *et al.*, 2015; Stockwell *et al.*, 2016; Adhikari *et al.*, 2020). The large variation in particle concentrations among the household cookings was mainly attributed to the differences in charcoal fuel, food, cooking condition, surrounding buildings, and the wind direction and speed.

Conclusions

The results of the investigation revealed that smoke from the firewood, and gas, contained chlorine, while plastic and mango did not produce bromine and iodine. The use of firewood in cooking released more iodine. The exposure of women, children, and the atmosphere to halogen may have negative effects which may be short-term or long-term. Although the emission of the halogen content of firewood in this study may not be at an alarming concentration, the constant use of the fuels may result in indoor and outdoor pollution. To overcome the effect of halogen from cooking fuels, it is better to use alternatives (fossil fuels).

References

ADHIKARI, S., MAHAPATRA, P.S., POKHERAL, C.P., PUPPALA, S.P. (2020). Cookstove Smoke Impact on Ambient Air Quality and Probable Consequences for Human Health in Rural Locations of Southern Nepal. International Journal of Environmental Research Public Health, 17: 550. https://doi.org/10.3390/ijerph17020550

AKAGI, S.K.; YOKELSON, R.J.; WIEDINMYER, C.; ALVARADO, M.J.; REID, J.S.; KARL, T.; CROUNSE, J.D.; WENNBERG, P.O. (2011) Emission factors for open and domestic biomass burning for use in atmospheric models. Atmospheric Chemistry and Physcis. 11, 4039–4072. https://doi.org/10.5194/acp-11-4039-2011

ALCALÁ, F.J. (2019) Usefulness of the Cl/Br ratio to identify the effect of reverse osmosis treated waters on groundwater systems. *Desalination*. 470, 114102. https://doi.org/10.1016/j.desal.2019.114102

SIMON, H., KIMURA, Y., MCGAUGHEY, G., ALLEN, D.T., BROWN, S.S., OSTHOFF, H.D., ROBERTS, J.M., BYUN, D. AND LEE, D. (2009) Modeling the impact of ClNO2 on ozone formation in the Houston area. Journal of GeophysicalResearch, 114, D00F03. https://doi.org/10.1029/2008JD010732

BEGUMA, B.A., PAULB, S.K., HOSSAINB, M.D., BISWASA, S.K., HOPKE, P.K. (2009) Indoor air pollution from particulate matter emissions in different households in rural areas of Bangladesh. Building and Environment, 44, 898–903. https://doi.org/ 10.1016/j.buildenv.2008.06.005

BETTINELLI M, SPEZIA S, MINOIA C, RONCHI A. (2002) Determination of chlorine, fluorine, bromine, and iodine in coals with ICP-MS and I.C. Atom Spectroscopy. 23:105–10.

CHANDRASEKARAN, S.R., HOPKE, P.K., RECTOR, L., ALLEN, G., LIN, L. (2012) Chemical Composition of Wood Chips and Wood Pellets. Energy Fuels, 26, 4932–4937. https://doi.org/10.1021/ef300884k

CHOWDHURY, Z., LE, L.T., AL MASUD., A., CHANG, K.C., ALAUDDIN, M., HOSSAIN, Z., HOPKE, P.K. (2012) Quantification of Indoor Air Pollution from Using Cookstoves and Estimation of Its Health Effects on Adult Women in Northwest Bangladesh. Aerosol and Air Quality Research. 12: 463–475. https://doi.org/10.4209/aaqr.2011.10.0161

DOI: 10.6092/issn.2281-4485/11572

DE BENOIST B, MCLEAN E, ANDERSSON M, ROGERS L. (2008) Iodine deficiency in 2007: Global progress since 2003. Food Nutrition. Bulletin: 29, 195–202. https://doi.org/ 10.1177/156482650802900305

ELEANNE D.S. VAN VLIET., KWAKUPOKU, A., DARBY W. J., PATRICK L. K., ROBIN., M.W., STEVEN N. C., LIVESY A., CHARLES Z., AND SETH OWUSU-AGYEI. (2013) Personal exposures to fine particulate matter and black carbon in households cooking with biomass fuels in rural Ghana. Environmental Research. 127: 40–48. https://doi.org/10.1016/j.envres.2013.08.009

FERNANDEZ, R.P., SALAWITCH, R.J., KINNISON, D.E. LAMARQUE, J.F., AND SAIZ-LOPEZ, A. (2014) Bromine partitioning in the tropical tropopause layer: Implications for stratospheric injection. Atmospheric Chemistry and Physcis. 14, 13391–13410. https://doi.org/10.5194/acpd-14-17857-2014

FLORES, E.M.M., MESKO, M.F., MORAES, D.P., PEREIRA, J.S.F., MELLO, P.A., BARIN, J.S.B., AND KNAPP, G. (2008) Determination of Halogens in Coal after Digestion Using the Microwave-Induced Combustion Technique. Analytical Chemistry. 80(6), 1865–187.

HOSSAINI, RYAN, CHIPPERFIELD, MARTYN P., SAIZ-LOPEZ, ALFONSO SL., FERNANDEZ, R.P., MONKS, S.A., BRAUER, P., GLASOW, R. (2016) A global model of tropospheric chlorine chemistry: Organic versus inorganic sources and impact on methane oxidation. Journal of Geophysical Research Atmospheres. 14, 271–297. http://dx.doi.org/10.1002/2016JD025756

KABATA-PENDIAS, A., MUKHERJEE, A.B. (2007) Trace Elements from Soil to Human, Springer-Verlag, Berlin.

KHAN, MN., NURS, CZ., ISLAM, MM., ISLAM, MR., RAHMAN, MM. (2017) Household air pollution from cooking and risk of adverse health and birth outcomes in Bangladesh: a nationwide population-based study. Environmental Health, 13;16(1):57. https://doi.org/10.1186/s12940-017-0272-y

LI, Q., BORGE, R., SARWAR, G., DE LA PAZ, D., GANTT, B., DOMINGO, J., CUEVAS, C.A., AND SAIZ-LOPEZWS, A. (2019) Impact of halogen chemistry on air quality in coastal and continental Europe: application of CMAQ model and implication for regulation. Atmospheric Chemistry. Physcis Discussion. https://doi.org/10.5194/acp-2019-171

LIM, SS., VOS, AD., FLAXMAN, G., DANAEI, K., SHIBUYA, H., ADAIR-ROHANI, M., AMANN, HR. (2012) A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010. Lancet, 380(9859). https://doi.org/10.1016/S0140-6736(12)61766-8

MCLEOD, J.A., WU, Z., SUN, B., LIU, L. (2015) The influence of the I/Cl ratio on the performance of $CH_3NH_3PbI_3$–xClx-based solar cells: why is CH_3NH_3I: $PbCl_2$ = 3:1 the "magic" ratio? Nanoscale. The Journal of Royal Society of Chemistry. http://dx.doi.org/10.1039/c5nr06217a

PENG B., WU, D., LAI, J., XIAO, H., LI, P. (2011) Simultaneous determination of halogens (F, Cl, Br, and I) in coal using pyrohydrolysis combined with ion chromatography. Fuel. http://dx.doi.org/10.1016/j.fuel.2011.12.011

SAIZ-LOPEZ, A., FERNANDEZ, R. P., ORDÓÑEZ, C., KINNISON, D. E., MARTÍN, J. C. G., LAMARQUE, J. F. AND TILMES, S. (2014) Iodine chemistry in the troposphere and its effect on ozone, Atmospheric Chemistry and Physics. 14(23), 13119–13143. https://doi.org/10.5194/acp-14-13119-2014

SIMPSON, W.R., BROWN, S.S., SAIZ-LOPEZ, A., THORNTON, J.A., AND VON GLASOW, R. (2015) Tropospheric Halogen Chemistry: Sources, Cycling, and Impacts. Chemical Reviews. 115, 4035–4062. https://doi.org/10.1021/cr5006638

SMITH, K., MEHTA, S., MACUSEZAHL-FEUZ, M. (2004) In: Ezzati M, Rodgers AD, Lopez AD, editors. Comparative quantification of health risks; the global and regional burden of disease due to selected major risk factors. Indoor air pollution from household use of solid fuels, vol 2. Geneva: World Health Organization, p. 1435–93. ISBN 92-4-158031-3

SMITH, K.R., SAMET, J.M., ROMIEU, I. BRUCE, N. (2000) Indoor Air Pollution in Developing Countries and Acute Lower Respiratory Infection in Children. Thorax. 55: 518–532. https://doi.org/10.1136/thorax.55.6.518

SMITH, KR., BRUCE, NK., BALAKRISHNAN, H., ADAIRROHANI, J., BALMES, Z, CHAFE, M., DHERANI, HD., HOSGOOD, S., MEHTA, D., POPE, E. (2014) Millions dead: how do we know and what does it mean? Methods used in the Comparative Risk Assessment of Household Air Pollution. Ann Rev of Public Health. 35: 185-206. https://doi.org/10.1146/annurev-publhealth-032013-182356

DOI: 10.6092/issn.2281-4485/11572

SONEJA, S.I., TIELSCH, J.M., CURRIERO, F.C., ZAITCHIK, B., KHATRY, S.K., YAN, B., CHILLRUD, S.N., BREYSSE, P.N. (2015) Determining Particulate Matter and Black Carbon Exfiltration Estimates For Traditional Cookstove Use In Rural Nepalese Village Households. Environmental Science and. Technology. 49, 5555–5562. https://doi.org/ 10.1021/es505565d

STOCKWELL, C.E., CHRISTIAN, T.J., GOETZ, J.D., JAYARATHNE, T., BHAVE,P.V.; PRAVEEN, P.S.; ADHIKARI, S.; MAHARJAN, R.; DECARLO, P.F.; STONE, E.A.; *et al*. (2016) Nepal Ambient Monitoring and Source Testing Experiment (NAMaSTE): Emissions of trace gases and light-absorbing carbon from wood and dung cooking fires, garbage and crop residue burning, brick kilns, and other sources. Atmospheric Chemistry and Physcis. 16, 11043–11081. https://doi.org/10.5194/acp-16-11043-2016

TAKEDA, A., YAMASAKI, TAKAKU, Y., HISAMATSU, S., TSUCHIYA, N. (2011) Determination of total contents of bromine, iodine and several trace elements in soil by polarizing energy-dispersive X-ray fluorescence spectrometry. *Soil Science and Plant Nutrition*. 57, 19–28. https://doi.org/ 10.1080/00380768.2010.548313

TISSARI, J.; LYYRÄNEN, J.; HYTÖNEN, K.; SIPPULA, O.; TAPPER, U.; FREY, A.; SAARNIO, K.; PENNANEN, A.S.; HILLAMO, R.; SALONEN, R.O.; et al. (2008) Fine particle and gaseous emissions from normal and smouldering wood combustion in a conventional masonry heater. Atmospheric. Environment. 42, 7862–7873. https://doi.org/ 10.1016/j.atmosenv.2008.07.019

UBUOH, E.A., NWAJIOBI, B. (2018) Implications of Different Household Cooking Energy on Indoor Air Quality in Urban and Semi-Urban Settlements in Imo, South Eastern Nigeria.*J.* Applied Science. Environmental. Management. 22(5): 725–72. https://doi.org/ 10.4314/jasem.v22i5.23

WORLD HEALTH ORGANIZATION (WHO). (2004) Iodine status worldwide. In the WHO Global Database on Iodine Deficiency, Eds. B de Benoist, M Andersson, Igli, B Takkouche, WHO, Geneva. ISBN 92-4-159200-1

WORLD HEALTH ORGANIZATION (WHO). (2010) Health in the green economy: Household energy sector in developing countries. Public Health and Environment Department. Accessed 12th November 2019.

WORLD HEALTH ORGANIZATION (WHO) (2016). Ambient air pollution: A global assessment of exposure and burden of disease. Public health, environmental and social determinants of health (PHE), Geneva, Switzerland: WHO. ISBN: 978-9-241511-353