

UNIVERSITY OF SOUTHERN DENMARK

ENVIRONMENTAL EXPOSURE AND PUBLIC HEALTH IMPACTS OF POOR CLINICAL WASTE TREATMENT AND DISPOSAL IN CAMEROON



PhD Dissertation

Peter Ikome Kuwoh Mochungong

Unit for Health Promotion Research
Faculty of Health Sciences
University of Southern Denmark

2011

PhD series A002: Unit for Health Promotion Research, 2011

ENVIRONMENTAL EXPOSURE AND PUBLIC HEALTH IMPACTS OF POOR CLINICAL
WASTE TREATMENT AND DISPOSAL IN CAMEROON

To be presented with the permission of the Faculty of Health Sciences of the University of Southern
Denmark for public examination on July 4th, 2011 at the auditorium of the University of Southern
Denmark in Esbjerg.

Institute for Public Health
University of Southern Denmark

Esbjerg, 2011

Publications of the University of Southern Denmark

Campusvej 55

5230 Odense M

Tel.: (0045) 6615 7999

Fax: (0045) 6615 8126

E-mail: press@forlag.sdu.dk

Copyright Peter Ikome Kuwoh Mochungong

ISBN: 978-87-91245-00-8

Cover photo: © Peter Ikome Kuwoh Mochungong

“Great effort is still needed to establish the provision of effective and universal healthcare, and with it the safe and effective disposal of clinical waste.”

~ J.I. Blenkarn

Supervised by:

- I. Gabriel Gulis, PhD
Associate Professor
Unit for Health Promotion Research
University of Southern Denmark
E-mail: ggulis@health.sdu.dk
- II. Morten Sodemann, M.D, PhD
Associate Professor
University Teaching Hospital Odense/ Institute for Public Health
University of Southern Denmark
E-mail: msodemann@health.sdu.dk

Committee chair:

Prof. Philippe Grandjean
Research Unit for Environmental Medicine
Institute for Public Health
University of Southern Denmark
E-mail: pgrandjean@health.sdu.dk

Committee members:

- I. Dr. Fabrizio Bianchi
Director of Research
Unit of Epidemiology
CNR Institute of Clinical Physiology
Via Moruzzi 1 - 56127 Pisa, Italy
Phone: +39-050-3152100/3153502
Fax: +39-050-3152095
E-mail: fabrizio.bianchi@ifc.cnr.it; fabriepi@ifc.cnr.it
- II. Dr. Peter Furu
Senior Adviser - Environmental Health and Health Impact Assessment
Head - WHO Collaborating Centre on Health and Environment in Sustainable Development
DBL - Centre for Health Research and Development
Faculty of Life Sciences
University of Copenhagen
Thorvaldsensvej 57
DK-1871 Frederiksberg C, Denmark
pfu@life.ku.dk
www.dbl.life.ku.dk
Phone: (0045) 3533 1430 (direct)
Fax: (0045) 3533 1433

CONTENTS

LIST OF ORIGINAL PUBLICATIONS	i
LIST OF ABBREVIATIONS	ii
ABSTRACT	iv
ABSTRAKT	vi
ACKNOWLEDGMENT	viii
1. INTRODUCTION	1
2. LITERATURE REVIEW	4
2.1. Definition, amount and characterization of clinical waste	4
2.2. Segregation, temporal storage and transportation	5
2.3. Treatment and disposal technologies	7
2.3.1. Incineration	8
2.3.2. Autoclaves and retorts	9
2.3.3. Microwaves and other heat and steam-based technologies	10
2.3.4. The use of chemicals	11
2.3.5. The use of landfills	11
2.4. By-products and environmental releases from clinical waste incineration	12
2.4.1. Bottom ash and fly ash	13
2.4.2. Inorganic releases	13
2.4.3. Organic releases	14
2.4.4. Gaseous emissions	17
2.5. Health impacts of clinical waste	18
2.6. Summary of the literature review	20
3. AIMS OF THE STUDY	22
4. BACKGROUND OF STUDY AREA	24
5. METHODOLOGY	29
5.1. Theoretical framework for HIA	29
5.2. Questionnaires	30
5.3. Sample collection and analysis	32
5.4. Data analyses	33
5.5. Ethical approval	33
6. RESULTS	34
6.1. Process of clinical waste management in Cameroon	34
6.2. Awareness of hospital workers	36
6.3. Standard of clinical waste incinerators in selected hospitals	37
6.4. Heavy metals and organic compounds in bottom ash	38
6.4.1. Heavy metals	38
6.4.2. Organic compounds	39
6.4.2.1. Polycyclic aromatic hydrocarbons (PAHs)	39
6.4.2.2. Dioxin-like (co-planer) polychlorinated biphenyls (PCBs)	41
6.4.2.3. Dioxins and furans (PCDDs and PCDFs)	42
6.5. Child morbidity	44
6.6. Health impact assessment process	46
6.6.1. Screening phase	46
6.6.2. Scoping phase	46
6.6.3. Risk appraisal phase	48
6.6.4. Evaluation and reporting	49

7.	DISCUSSION.....	50
7.1.	Waste management analysis.....	50
7.2.	Awareness of hospital workers.....	52
7.3.	Standard of clinical waste incinerators.....	53
7.4.	Heavy metals and organics in bottom ash.....	54
7.4.1.	Site conceptual model and potential exposure pathways.....	57
7.4.2.	Metal toxicity.....	59
7.4.3.	Toxicity equivalence quantities (TEQs).....	60
7.5.	Morbidity and poor clinical waste disposal.....	61
7.6.	Prospective policy development through HIA.....	64
8.	CONCLUSION.....	67
8.1.	Further research perspectives.....	71
9.	REFERENCES.....	72

LIST OF ORIGINAL PUBLICATIONS

This study is based on the following original publications, submitted manuscripts and abstract.

PUBLICATIONS AND MANUSCRIPTS:

- I. Mochungong, P.I.K., Gulis, G., Sodemann, M, (2010). Hospital workers' awareness of health and environmental impacts of poor clinical waste disposal in the Northwest Region of Cameroon. *Int. J. Occup. Environ. Health*, 16; 53-59.
- II. Mochungong, P.I.K (2010). The plight of clinical waste pickers: evidence from the Northwest Region of Cameroon. *J Occup Health*, 20; 52(2):142-5.
- III. Mochungong, P.I.K., Gulis, G., Sodemann, M. (2010). Clinical waste incinerators in Cameroon - a case study. *International Journal of Healthcare Quality Assurance*, (in press).
- IV. Mochungong, P.I.K. Comparative analysis of dioxin-like PCBs, PCDD/Fs and PAHs in bottom ash from an open fire pit and an engineered medical waste incinerator. *Environ. Monit. Assess.*, (Submitted).
- V. Mochungong, P.I.K., Gulis, G., Sodemann, M. Morbidity among children living around clinical waste treatment and disposal site in the Northwest region of Cameroon: a case report. *Journal of Public Health in Africa*, DOI: [10.4081/jphia.2011.e13](https://doi.org/10.4081/jphia.2011.e13).
- VI. Mochungong, P.I.K., Gulis, G. Health impact assessment for a prospective clinical waste management policy for Cameroon. *International Journal of Healthcare Management and Planning*, (Submitted).

ABSTRACT:

- I. Stuart Batterman, Peter I.K. Mochungong, Debora Bossemeyer. Risk assessment tools for incineration and other disposal options for medical waste: applications in Africa. Session 103 – environmental management tools, uncertainty and decision making; SETAC Europe 20th Annual Meeting, 23rd – 27th May 2010 Seville, Spain (Abstract).

The articles are reprinted with permission from all the publishers.

LIST OF ABBREVIATIONS

Ag = Silver
Al₂O₃ = Aluminum oxide
As = Arsenic
APCDs = Air pollution control devices
APCS = Air pollution control system
ATSDR = Agency for toxic substances and disease registry
B[a]A = Benzo [a] anthracene
B[a]P = Benzo [a] pyrene
B[b]F = Benzo [b] fluoranthene
B[g,h,i]P = Benzo [g,h,i] pyrene
B[k]F = Benzo [k] fluoranthene
Ba = Barium
BDL = Below detection limit
CaO = Calcium oxide
Cd = Cadmium
Chr = Chrysene
Cr = Chromium
Cu = Copper
CCMS = Committee on challenges of the modern society
CDC = Centre for Disease Control
CI = Confidence interval
CO = Carbon monoxide
CWM = Clinical waste management
D[a,h]A = Dibenzo [a,h] anthracene
EI = Engineered incinerator
EIA = Environmental impact assessment
Fe = Iron
Flu = Fluoranthene
GC-HRMS = Gas chromatography – high resolution mass spectrometry
GC-MS = Gas chromatography – mass spectrometry
Hg = Mercury
HpCDD/F = Heptachlorinated dibenzo dioxin/ furan
HxCDD/F = Hexachlorinated dibenzo dioxin/ furan
HBV = Hepatitis B virus
HCl = Hydrogen chloride
HCV = Hepatitis C virus
HCW = Healthcare worker
HCWH = Healthcare without harm
HIA = Health impact assessment
I[1,2,3-cd]P = Indeno [1,2,3-cd] pyrene
I-TEQ = International – Toxic equivalent quantity
IARC = International Agency for Research on Cancer
K = Potassium
LOD = Limit of detection
Mn = Manganese
MSWI = Municipal solid waste incinerator
MW = Molecular weight

mg/kg = milligram per kilogram
Na = Sodium
Ni = Nickel
NATO = North Atlantic Treaty Organization
NGO = Non-governmental organization
NO_x = Oxides of nitrogen
ng/g = nanogram per gram
O₂CDD/F = Octachlorinated dibenzodioxin/ furan
OFP = Open fire pit
OTA = Office of Technological Assessment (United States Congress)
Pb = Lead
PeCDF = Pentachlorinated dibenzofuran
PAHs = Polycyclic aromatic hydrocarbons
PCBs = Polychlorinated biphenyls
PCDD/Fs = Polychlorinated dibenzodioxins/ furans
PDR = People's Democratic Republic
PI = Percutaneous injury
PM = Particulate matter
PVC = Polyvinyl chloride
pg = picogram
SiO₂ = Silicon dioxide
Sn = Tin
SD = Standard deviation
SO₂ = Sulphur dioxide
Ti = Titanium
TCDD/F = Tetrachlorinated dibenzodioxin/ furan
TEF = Toxicity equivalent factor
TEQ = Toxic equivalent quantity
U.S. EPA = United States Environmental Protection Agency
UNCED = United Nations Conference on Environment and Development
VOCs = Volatile organic compounds
WHO = World Health Organization
Zn = Zinc
µg/kg = microgram per kilogram

ABSTRACT

Poor clinical waste management, especially treatment and disposal methods, threaten the environment and public health in most developing countries. Inefficient segregation and transportation techniques increase the potential for the transmission of blood borne pathogens while uncontrolled and sub-standard burning increase potential exposure to organic compounds and heavy metals which might be present in gaseous and solid by-products. This study addressed issues relating to the improper management of clinical waste in Cameroon: assessing the management method (collection to disposal) and three randomly selected clinical waste incinerators. Environmental exposures to pollutants in solid by-products (bottom ash) from sub-standard incineration were also evaluated.

In April 2008, a study aimed at assessing clinical waste management was conducted in the Northwest region of Cameroon. Three hospitals: Bamenda Regional Hospital, Bansa Baptist Hospital and Bali District Hospital were selected for the study. The incinerators at each of the aforementioned hospitals were evaluated for design and operational efficiency. Bottom ash was collected from each of the incinerators for chemical analysis. A small exploratory study was designed to evaluate respiratory, intestinal and skin infections among children living close and with access to poor clinical waste disposal location. Health impact assessment (HIA) was used as a tool to establish evidence-based needs and prerequisites for a prospective clinical waste management policy for Cameroon.

Significant flaws relating to collection, segregation, transportation and treatment and disposal methods were common in the three hospitals. Collection containers were not appropriately distinct in any way, and they were sometimes broken and overloaded. Segregation was weak and ineffective and transportation was done by waste pickers with complete disregard for safety. Co-disposal was observed in open-surface dumps and open landfills. Anatomical (tissue) waste was disposed in secured landfills. Intermittent open-burn sites and sub-standard incineration were common and practiced within the premises of the three hospitals. 57.5% and 18.8% of hospital workers had basic and appropriate knowledge of clinical waste respectively; 55% and 20% had adequate and inadequate understanding of health impacts or poor clinical waste management respectively. Awareness and unawareness of environmental impacts was demonstrated by 37.5% and 62.5% of the hospital workers respectively. 21.2% and 78.8% respectively knew and did not know the existence of policies and/ or guidelines on efficient clinical waste management.

Additionally, 31.2% and 68.8% respectively knew and did not know of public concerns on the negative impacts of current management methods.

Bottom ash from the three clinical waste incinerators contained high amounts of selected heavy metals, especially Pb, which was 230 mg/kg in one of the incinerators. For logistics reasons, organic compounds were not analyzed in the bottom ash samples from Cameroon. However, results of organic compounds in bottom ash samples from OFP and an EI in Mozambique had high levels of 15PAHs, dioxin-like PCBs and PCDD/F. Total TEQ for 15PAHs was 729.24 ng TEQ/ g and 2801.25 ng TEQ/ g in EI and OFP respectively. Total TEQs for dioxin-like PCBs and PCDD/Fs in EI was 0.016 ng TEQ/ g, 0.272 ng TEQ/ g and 0.074 ng TEQ/ g respectively. On the other hand, their total TEQs in OFP was 0.011 ng TEQ/ g, 0.386 ng TEQ/ g and 0.1061 ng TEQ/ g respectively. The results indicate that only PAHs are important from a toxicity perspective due to high TEQs in both bottom ash samples. Dioxins and dioxin-like compounds pose less of a threat from a toxicity standpoint to the population. Paired t-test statistical analysis revealed statistically significant (p -value = 0.0001) difference in the mean of the 15PAHs in both ash samples, while the mean difference of dioxin-like PCBs (p -value = 0.09), PCDDs (p -value = 0.27) and PCDFs (p -value = 0.25) were statistically insignificant.

Risk ratios for respiratory, intestinal and skin infections were 3.54 (95% CI, 2.19 - 5.73), 3.20 (95% CI, 1.34 - 7.60) and 1.35 (95% CI, 0.75 - 2.44) respectively. These results should be interpreted carefully as a study with larger sample size and enhanced study design will be needed to more definitively investigate these preliminary results. Through the HIA process, stakeholders were able to come up with evidence-based recommendations to improve the process of clinical waste management in Cameroon. Some of the recommendations were to harness and strengthen political and economic will towards the development and implementation of a robust policy on efficient clinical waste management. Others include the involvement of all stakeholders in the policy making process, promote research and generate reliable data in the area, attract international technical and financial aid in the sector and promote training and awareness campaigns in the sector.

ABSTRAKT

Utilstrækkelig håndtering af klinisk affald, især metoder til behandling og bortskaffelse, truer miljøet og folkesundheden i de fleste udviklingslande. Ineffektive metoder til sortering og transport øger risikoen for overførsel af blodbårne patogener, mens ukontrolleret afbrænding ved middelmådige metoder øger en potentiel eksponering af polyhalogenerede forbindelser og tungmetaller. Dette studie undersøgte utilstrækkelig håndtering af klinisk affald i Cameroun og vurderede miljøeksponeringer af forurenende stoffer fra biprodukter (bundaske) fremkommet på grund af middelmådige metoder til behandling og bortskaffelse såsom forbrænding. Håndteringsmetoden (indsamling til bortskaffelse) og tre tilfældigt udvalgte kliniske forbrændingsanlæg blev evalueret. Der blev udført en sygelighedsundersøgelse i lokalområder omkring kliniske lossepladser med afsæt i en hypotese om, at spredning og eksponering af forurening herfra medfører en stigning i sygelighed hos børn.

I april 2008 blev en undersøgelse udført med henblik på at vurdere klinisk affald i den nordvestlige region i Cameroun. Tre hospitaler: Bamenda Regional Hospital, Bansa Baptist Hospital og Bali District Hospital blev udvalgt til undersøgelsen. Forbrændingsanlæggene på hvert af de ovennævnte hospitaler blev vurderet i forhold til design og operationel effektivitet. Der blev indsamlet bundaske til senere analyse for tungmetaller, dioxiner (PCDD) og furaner (PCDF), polychlorerede biphenyler (PCB) og polycykliske aromatiske kulbrinter (PAH) fra hvert forbrændingsanlæg. Sygelighed i form af respiratoriske lidelser, intestinale lidelser og infektioner i huden blandt børn, der bor tæt på og har adgang til steder med utilstrækkelig håndtering af klinisk affald blev evalueret. Derudover blev der udført Sundhedskonsekvensvurderinger (SKV) på en prospektiv politik for håndtering af klinisk affald i Cameroun.

Dette studie blev en del af en bredere debat om betydningen af utilstrækkelig håndtering af klinisk affald i forhold til miljømæssige risici og den offentlige sundhed. Utilstrækkelige teknikker til sortering og ineffektive metoder til behandling og bortskaffelse blev forslået som vigtige kilder til sådanne risici. Metoder til indsamling, sortering, transport, behandling og bortskaffelse blev alle fundet utilstrækkelige i de tre sygehuse. Beholdere til indsamling var ikke tilstrækkeligt adskilt, og de blev undertiden ødelagt og overbelastet. Sorteringsteknikkerne var dårlige og ineffektive, og transporten blev udført af affalds opsamlere med ringe eller ingen beskyttelse. Det blev observeret, at deponering oftest fandt sted på åbne lossepladser. Anatomisk affald (væv) blev bortskaffet i sikrede deponeringsanlæg. Sporadiske pladser med åben ild og anden middelmådig forbrænding var almindelige og blev anvendt på alle tre hospitaler. Medarbejderne på de udvalgte hospitaler havde

grundlæggende et kendskab til klinisk affald, men en god procentdel af dem var hverken bekendt med miljøpåvirkningerne forbundet med utilstrækkelig håndtering af klinisk affald eller politikker og retningslinjer for effektiv kliniske affaldshåndtering. De fleste af hospitalernes medarbejdere havde desuden ikke opfattet nogen form for bekymring fra offentligheden i forhold til de eksisterende og utilstrækkelige metoder for behandling og bortskaffelse. De udviste imidlertid tilstrækkelig viden om og forståelse for de sundhedsmæssige konsekvenser af utilstrækkelig klinisk affaldshåndtering.

Bundaske fra de tre forbrændingsanlæg til kliniske affald indeholdt store mængder af udvalgte tungmetaller, især bly (Pb), som blev målt til 230 mg/kg i et af forbrændingsanlæggene. Af logistiske årsager blev polyhalogenerede forbindelser ikke analyseret i bundaske prøver fra Cameroun. Men resultaterne af polyhalogenerede stoffer i bundaske prøver fra åben ild afbrænding og et manipuleret forbrændingsanlæg i Mozambique havde høje niveauer af 15PAH'ere, dioxinlignende PCB'ere og PCDD/F'ere. Koncentrationerne var højere i bund aske prøverne fra åben ild forbrænding end fra det manipulerede forbrændingsanlæg. T-test statistisk analyse viste betydelig forskel i niveauet for 15PAH'ere i askeprøverne, mens indholdet af dioxinlignende PCB og PCDD/F ikke var statistisk signifikant. Ifølge sygelighedsundersøgelsen var risikorationen for respiratoriske lidelser samt tarm- og hudinfektioner for eksponerede børn i forhold til ueksponerede børn 3,54 (95 % CI, 2,19 til 5,73), 3,20 (95 % CI, 1,34 til 7,60) og 1,35 (95 % CI, fra 0,75 til 2,44). Gennem SKV processen, blev de berørte parter i stand til at komme med anbefalinger til forbedring af processen for klinisk affald i Cameroun. Nogle af anbefalingerne var at udnytte og styrke den politiske og økonomiske vilje til udvikling og gennemførelse af en styrket politik for effektiv håndtering af klinisk affald. Andre anbefalinger omfattede inddragelse af alle interessenter i den politiske beslutningsproces, fremme forskning og generere pålidelige data på området, tiltrække international teknisk og finansiel støtte i sektoren og fremme uddannelse og oplysningskampagner i sektoren.

ACKNOWLEDGMENT

I gratefully acknowledge the support, and thank all my colleagues at the Unit for Health Promotion Research. You all contributed to the success of this project in very different ways. I am particularly thankful to my principal supervisor Assoc. Prof. Gabriel Gulis and our Unit Head Prof. Arja Aro. You (plural) were relentless in your efforts towards the success of this project, and you have both had a positive influence in my academic career. I also acknowledge my co-supervisor Assoc. Prof. Morten Sodemann for his relevant and thoughtful comments. They significantly improved the quality of this work.

I will also like to mention the contribution of Dorte Spangsmark, laboratory technician at Aalborg University Esbjerg. She was particularly helpful in the laboratory analysis of heavy metals in the bottom ash samples from Cameroon. I offer warm thanks to Prof. Stuart Batterman, Department of Environmental Health at The University of Michigan for giving me the opportunity to work with him as a short-term Research Scholar, and for initiating and facilitating a technical visit trip to Mozambique. Both experiences added positive dimensions in this project and my future career. This thesis had an external reviewer in the person of Dr. M. Coutinho of IDAD, Portugal. His contribution to the quality of the work was priceless.

I also acknowledge the support and encouragement from the staff at the study locations. You all saw the timeliness of such a study in Cameroon and were also enthusiastic about its outcome. I also extend my gratitude to all my field assistants who collected data on the morbidity study and my dad, Dr. B.P. Kuwoh who coordinated them in my absence and regularly sent the collected data to me. I also salute my mum, Ms. J.E. Ikome for her unflinching support and encouragement.

Above all, I am grateful to God Almighty!

Esbjerg, 2011

1. INTRODUCTION

Efficient clinical waste management is a major problem in Africa, and Cameroon in particular. Waste is seldom segregated at the points of generation and compatibility and reliability issues abound when it comes to current treatment and disposal practices. Reflecting on this, there is potential for environmental exposure to toxic emissions from sub-standard incinerators (poor combustion conditions) and nuisance arising from foul stench, not leaving out attraction and proliferation of vermin. Even though there is some uncertainty around the degree of risks posed by clinical waste, there is rational agreement that illegal and uncontrolled disposal threatens public health. For example, frequent outbreaks of typhoid, diarrhea and cholera in neighborhood communities can be associated with poor handling of such wastes (Fongwa, 2002).

Estimates on the amount and type of clinical waste produced by healthcare establishments vary, in no particular order, according to clinics, health centers and hospitals depending on the size and capacity (number of beds) and types of services on offer. The inclusion of other factors such as country, location of the facility (remote or urban) and access in terms of roads further compounds this variability. A joint report by the WHO and the World Bank state that small rural clinics generate small amounts of waste, usually <10 kg of sharps per month; small district hospitals generate 1 kg/bed/day; general hospitals generate 2 kg/bed/day while tertiary or major teaching hospitals generate 4 kg/bed/day (WHO and World Bank, 2005). Kezaala (2002) drew attention to the fact that routine immunization campaigns in Africa generate large amounts of waste. For example, the 2001 measles mass immunization campaign covering 6 countries in West Africa targeted over 16 million children and generated over 300 tons of injection-related waste (Kezaala, 2002). Estimates by the WHO showed that routine immunization of less than one year old children and women of child bearing age with tetanus toxoid accounted for over one billion injections in 1998, while measles eradication activities accounted for another 200 million injections in the same year (WHO, 1999).

Such amount of waste presents treatment and disposal challenges. Besides preventing cross contamination during the management process, selecting a suitable and environmentally friendly method is a top challenge. In developing countries, methods such as dumping in open landfills, surface dumping and use of sub-standard incinerators are common (Coker et al. 2009; Hassan et al. 2008; Mbongwe et al. 2008; Sawalem et al. 2008). A survey conducted by the WHO in 22 developing countries reveal that 18% to 64% of health care establishments do not

use proper clinical waste treatment and disposal technologies (WHO, 2005). In the western world, treatment and disposal methods are in conformity with certain international regulations characterized by standard incineration with air pollution control devices (APCD) and the application of a wide range of non-combustion technologies.

Incineration, as a preferred choice for treating clinical waste, has similar merits and demerits as with the incineration of municipal waste (Jang et al, 2006). Some of the merits include significant reduction in volume and size including little processing time for treatment of the waste while the demerits include high initial and maintenance cost and potential pollution risks (OTA, 1988). Sub-standard incineration results in the release of toxic chemicals into the environment capable of travelling long distances in the air before eventually depositing to earth (Singh and Prakash, 2007). Examples of such chemicals include polychlorinated dibenzodioxins and dibenzofurans (PCDD/F), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). Some congeners of these compounds are known human carcinogens (ATSDR, 1994; 1998; 2002; IARC, 1997; Mohee, 2005; U.S.EPA, 1994). Solid by-products from the incinerators are also potential carriers of different types of metals, metal oxides and the aforementioned organic compounds.

Unregulated clinical waste treatment and disposal has been linked to several public health threats. Solberg (2009) disclosed that in March 2009, 240 people in the Indian state of Gujarat contracted hepatitis B after receiving medical care with previously used syringes acquired through the illegal trade of clinical waste. The Reuters News Agency (Reuters News, 2008) reported that individuals scavenging for reusable items in Kabul, Afghanistan, sustained infectious injuries after the byproducts of a mass immunization campaign of 1.6 million against polio were poorly discarded in municipal waste bins. The governments of these countries, including others in similar situations, are forced to preemptively react either as an excuse for the status quo or as efforts to put the sector in conformity with international standards. As examples of the latter, the government of Cameroon (in partnership with the World Bank) and the government of Mozambique (in partnership with Jhpiego- an affiliate of The John Hopkins University) launched procedures for the development of a national clinical waste management policy in May 2008 and May 2010 respectively. It is expected that such strong and sustained political commitment, supplemented by social and educational programs will almost certainly curb public apprehension on associated hypothetical risks and guarantee meaningful short-term improvements.

This dissertation summarizes original research work on the clinical waste management crisis and subsequent impacts on health as a result of poor treatment and disposal in Cameroon with experiences from Mozambique. Emphasis was placed on environmental exposures and health risks of organic and inorganic compounds present in solid byproducts such as bottom ash produced by on-site sub-standard incinerators and other open burn sites. Through a prospective HIA, stakeholders highlighted areas and issues government can consider in drawing up and implementing a clinical waste management policy and action plan for Cameroon.

It is important to note that this dissertation is a summary of important findings from six original manuscripts prepared during the course of the project. Detailed information on specific background themes, methodology and data analysis is available in the manuscripts in question. With permission from the publishers, these manuscripts are printed with the hard copy of this dissertation only, and are thus not available with the on-line version.

2. LITERATURE REVIEW

2.1. Definition, amount and characterization of clinical waste

Clinical waste management (CWM) drew attention when it was, for the first time, included in the agenda and discussed at the Earth Summit hosted by the United Nations Conference on Environment and Development (UNCED, 1992). CWM has since become an issue of scientific research and political deliberations because of its potential occupational hazards, purported impacts on the environment and public health and policy issues of national interest (WHO, 2001). Many synonyms to clinical waste exist, and they are currently used interchangeably (Moritz, 1995) in different parts of the world and in different scientific journals. Some of the easily come across synonyms are medical waste, hospital waste and bio-medical waste. The WHO uses the term 'healthcare waste' in reports and other official publications.

Clinical waste has often been defined differently by countries and researchers alike, international NGOs and other global institutions. Al-Mutair et al (2004) defined clinical waste as any solid or liquid waste, capable of causing infectious diseases, generated as a result of patient diagnosis, treatment and through the immunization of humans or animals or in related research. Phillips (1999) defined clinical waste as waste arising from the investigation, treatment or medical care of patients, while Abor and Bouwer (2008) focuses their definition to include all types of wastes produced by health facilities such as general hospitals, medical centers and dispensaries. The WHO considers it to be a byproduct of healthcare that includes sharps, non-sharps, blood, body parts chemicals, pharmaceuticals, medical devices and radioactive materials (WHO, 2005a). These differences in definition according to Muhlich et al (2003), is based on how much leeway the definitions allow for optimized treatment and disposal practices in the hospitals or elsewhere and the amount of considerations given to health and safety of patients and personnel.

The WHO suggests that around 80% of clinical wastes are non-hazardous (comparable to domestic waste), 15% are infectious (cultures and stocks of infectious agents, wastes from infected patients, wastes contaminated with blood and its derivatives, discarded diagnostic samples, infected animals from laboratories, and contaminated materials and equipment) and anatomic (recognizable body parts and carcasses of animals) wastes and the remaining 5% is made-up of sharps (1%), toxic chemicals and pharmaceuticals (3%) and genotoxic and radioactive waste (1%) (WHO, 2007). These traditional estimates, according to Azage and Kumie (2010), are not consistent for many developing countries. According to the authors, 25%

of clinical waste produced in Pakistan is hazardous, 26.5% in Nigeria and 2-10% in other sub-Saharan Africa countries. Manyela and Lyasenga (2010) state that urban health centers in Tanzania generate 50% of the country's clinical hazardous waste. Sakar et al (2006) identified higher clinics and diagnostic centers as being responsible for 36.03% of hazardous clinical waste produced in Bangladesh. Recording daily hospital averages of clinical waste, including the specific amount produced per bed/day and factoring this amount in to relative mathematical equations is a major way of quantifying the amount of clinical waste produced in hospitals. But since health care establishments differ in ways previously mentioned, including size of medical staff and proportion of reusable items used in the establishment, such a technique produces results relative to each healthcare establishment (Tsakona et al, 2007). US hospitals generate an estimated 6,670 tons of clinical waste per day (Rutala and Mayhall, 1992), 3,8 kg/bed/day in Portugal (Alvim Ferraz et al (2000)) and 1 kg/bed/day is generated in Thailand (Kerdsuwan, 2000). It is important to bear in mind that only a fraction of healthcare institutions contribute to the aforementioned figures as data from private physicians' offices, dentists, veterinarians, medical clinics, laboratories, long-term care facilities and free standing care blood banks are unreliable and often unavailable (Rutala and Mayhall, 1992).

Determining which portion or components of clinical waste is infectious is challenged by its inherent heterogeneous nature and definitional problems (OTA, 1998). No tests currently exist to objectively determine whether waste is infectious or not (Rutala and Mayhall, 1992). The U.S. EPA and Centers for Disease Control, despite their discrepancies in clarifying the term "infectious waste", have designated pathological waste, blood and blood products, contaminated sharps (scalpels, needles and blades) and microbiological waste (cultures and stocks) as infectious (OTA, 1998). In general, for waste to be infectious, it has to contain enough virulence capable of causing an infectious disease including a portal of entry in a susceptible host.

2.2. Segregation, temporal storage and transportation

Thorough segregation and temporal storage of clinical waste in to its infectious and non-infectious components is an important process in any efficient CWM effort. The process guarantees reduction in the amount of infectious waste requiring special treatment and curbs potential occupational and operational risks to health care employees and by extension, the general public. Despite these merits, the process of segregation is overwhelmed with challenges

that are pretty obvious in health care settings in the developing world. Patil and Shekdar (2001) reported that lack of awareness and training in clinical waste segregation technique is the major reason why clinical waste is collected in mixed form in India. Similar observations were reported by Phengxay et al (2005) in Lao PDR, Mbongwe et al (2008) in Botswana and Bdour et al (2006) in Jordan.

Another challenge to a successful clinical waste segregation process is the waste receptacles at the generation points and how to differentiate them according to the type of waste they receive. According to the US Congress Office of Technology Assessment (OTA, 1988), the integrity of packaging, particularly of such items as sharps, is critical to ensuring the containment of wastes during their collection, storage, and transportation. The WHO (WHO, 1985) and the U.S.EPA (U.S.EPA, 1986) recommend color coded polyethylene bags with secure closure to facilitate segregation, storage and identification of infectious and non-infectious waste. Red color bags, and often with a biological hazard mark on it as shown in figure one, are often used as receptacles for infectious clinical waste. Considering that infectious clinical waste can both be bulky (pathological waste, various absorbents and isolation wastes) and contain sharps such as lancets, scalpels and needles and blades, Rutala and Sarubbi (1983) and Slavik (1987) recommend the polyethylene bag be manufactured according to the American Society of Testing and Materials standard (no. D 1709-75) of tear resistance based on the mil gauge thickness and a dart drop test.

Figure 1: Red bag for infectious clinical waste with biological hazard mark.



According to Luttrell et al (2003), temporal storage refers to the interim period between generation and transportation either to an on-site treatment facility or to an off-site location. The space for temporal storage according to Marinkovic et al (2008) should be out of reach of patients and staff, properly marked and accessible only to authorized personnel. Rutala and Sarubbi (1983) added that such a space should be disinfected regularly and be maintained at an appropriate temperature, to guard against microbial putrefaction and growth (OTA, 1988).

There is not yet a universally accepted standard period of time that the waste can be stored prior to treatment and disposal, but the U.S.EPA (U.S.EPA, 1986) recommends this time be kept as short as possible.

Transportation of clinical waste in medical establishments occurs in two ways; the first is from the source of generation to an on-site treatment or disposal facility while the second involves removal from a source of generation to an on-site temporal storage facility before eventual transportation to an off-site treatment and disposal facility. On-site transportation of clinical waste in most cases depends on the time it takes for the receptacle in question to fill-up, and because this depends on issues such as the size and services offered by the facility and varies according to ward and units, it is not uncommon to find receptacles with over-filled waste (Coker et al, 2009). On-site clinical waste transportation in Libya, as recounted by Sawalem et al (2008), is done via uncovered trolleys while in Nigeria, Coker et al (2009) reported that clinical waste in health care facilities is transported on shoulders or with bare hands. In an effort to minimize any potential risks involved in such practices, the U.S.EPA (U.S.EPA, 1986) recommends placement of wastes in rigid and leak proof containers including the avoidance of activities that can rupture the container.

Off-site transportation of clinical waste according to Luttrell et al (2003) takes place on land using vehicles, even though there is a likely risk of accidental release of hazardous materials in to the environment. According to the author, the waste is typically contained in high-volume bulk storage tanks or low-volume storage drums and the storage containers and vehicles transporting such wastes should be placarded with the bio-hazard mark while on transit. Other important issues in off-site clinical waste transportation according to the U.S. Congress Office of Technology Assessment (OTA, 1988) that need to be addressed include creating and constantly updating a database and keeping track of infectious clinical waste and the containment of the waste at transfer stations.

2.3. Treatment and disposal technologies

In selecting clinical waste management technologies, the terms “treatment” and “disposal” are often wrongly used interchangeably. Luttrell et al (2003) clarify “treatment” as an alteration of a waste stream or contaminated site in order to reduce, eliminate or immobilize hazardous constituents, while “disposal” implies disregard for return, and is thus considered to be permanent storage or release. As per the clarifications of the two terms, examples of

treatment technologies include incineration and pyrolysis, microwave and autoclave sterilization and disinfection with chemicals, hydroclave and rotoclave (Alagoz and Kocasoy, 2007).

Disposal technologies in contrast include the use of landfills and other surface impoundment techniques.

2.3.1. Incineration

Clinical waste incineration is a thermal treatment process in which elevated temperatures reduce the size and volume of the waste stream into emissions and bottom ash; which in the case of emissions require further attention, and in bottom ash, must be treated as hazardous or special waste (McRae, 1997). Because most medical establishments incinerate both infectious and general waste, no reliable data exist on the amount of incinerated clinical waste. However, the U.S.EPA has estimated that about 80% of the total amount of clinical waste generated in the U.S. is incinerated (Lee et al, 1988); in either of the following three commonly used clinical waste incinerators of controlled air, multiple chamber air and rotary kiln models (Hsieh and Confuorto, 1992; OTA, 1988). Such models are rare to find in developing countries for reasons tied to lack of/ and or mismanagement of human, material and financial resources. Improvised burn units such as pit and drum burners according to Diaz et al (2005), are commonly used for clinical waste incineration in developing economies because they are relatively inexpensive, easy to build and require little or no maintenance.

Standard clinical waste incinerators, common in advanced economies, are two chambered, and operate at extremely high temperatures. The primary chamber, which is usually located close to the loading area, dries and burns clinical waste in conditions of 'starved air'. That is, it operates at between 40% - 80% its oxygen stoichiometric requirement (Dempsey and Oppelt, 1993; OTA, 1988). The secondary chamber is usually located next to or above the primary chamber and operates in conditions of excess oxygen, that is, between 100% - 150% its stoichiometric requirement. The secondary chamber essentially functions as a pollution control device as combustible gas from the primary chamber mixes with the excess air and is burned at elevated temperatures (Dempsey and Oppelt, 1993; OTA, 1988).

The location of medical establishments within communities has raised public skepticism on the use of on-site incineration (particularly in developing economies) as a technique for clinical waste management. Niessen (2002) identified public distrust and unreliability in equipment, operation and maintenance and staffing problems as the source of the skepticism.

According to the U.S. National Academy of Science (2000), the potential risks to human health that might result from the emission of pollutants during the incineration process and possible social, economic, and psychological effects associated with living or working near an incineration facility further contribute to the skepticism. Such distrust and skepticism has led to the governments in some countries like the U.S. and Canada and the European Community to introduce stringent air pollution control standards for clinical waste incinerators (Barkely et al, 1983; Williams, 1994).

2.3.2. Autoclaves and retorts

The use of moist heat in autoclaves and retorts according to Diaz et al (2005) has achieved much success as a clinical waste treatment technique prior to disposal; possibly in a landfill, in the last decade. A boiler generates the steam that is required for the sterilization process. Heat resistant and steam permeable plastic bags containing infectious waste are then placed in a pressurized chamber where the boiler-generated steam at temperatures of $\geq 121^{\circ}\text{C}$ is introduced to the waste for an estimated duration of 15-30 minutes (Diaz et al, 2005; Krisiunas, 2001). Vents in the autoclave are then opened at the end of the treatment process to release the steam through a condenser, and when the waste has sufficiently cool down, it can then be carried to a site for shredding and size reduction before final disposal (Diaz et al, 2005; OTA, 1990). In order to ensure that pathogens in the waste have adequately been destroyed, *Bacillus stearothermophilus* is introduced in to the autoclave together with the waste at the onset of each treatment cycle and then measured at the end of the cycle via spore tests. Complete elimination of the organism; which requires steam exposure for about 90 minutes, guarantees sufficient pathogen destruction in the clinical waste (OTA, 1988). The *Bacillus stearothermophilus* approach is more conservative as the 90 minutes duration exceeds standard operating procedures (Reinhardt and Gordon, 1991).

Just like in any clinical waste treatment technology, the use of autoclaves also has its shortcomings. Many organic reactions are accelerated at extremely high temperatures and pressurized steam is a good medium for volatilizing organic compounds. Therefore, depending on the amount and composition of the waste, a variety of organic species may be emitted during each treatment cycle (Krisiunas, 2001.). As a result, only items such as sharps and cultures, blood contaminated items, surgical residues and other absorbents like bandages and non-chemical laboratory waste can be autoclaved (Diaz et al, 2005). The water used for steam

generation needs to be properly treated to prevent salt and other chemical build-up on the walls of the boiler as this can reduce heat transfer. Initial and maintenance cost, including skilled operational man-power is also another put-off in the use of autoclaves especially for developing nations. Other difficulties in using autoclaves according to the U.S. Congress, Office of Technology Assessment (OTA, 1988) includes the more limited capacity of most autoclaves and the time consuming process for each treatment cycle.

2.3.3. Microwaves and other heat and steam-based technologies

Microwave treatment of clinical waste is essentially a steam-based disinfection process whereby moist heat and steam generated by microwave energy destroy pathogens which might be present in the waste stream (HCWH Europe, 2004). Consequently, and contrary to common thought, clinical waste disinfection in a microwave chamber is not carried out by electromagnetic radiations. According to Diaz et al (2005), microwave units can function in batch and continuous processes, and either is more efficient when the material handling equipment, the disinfection chamber and the environmental control equipment all function properly. The waste holding time within the microwave unit is estimated to last 30 minutes, after which the waste is allowed to cool and later transported for final disposal. Just as in autoclaves, test pathogens could be introduced into the microwave together with the waste stream and no growth or complete destruction of the test pathogen guarantees disinfection of other microorganisms. Volatile organic compounds have been found to be within permissible limits in workers' areas of microwave waste treatment facilities (Cole, 1998). This can however, only be possible with effective segregation, such that harmful chemicals do not get into the waste stream.

Microwave treatment technology is limiting in that it can handle only specific waste types such as sharps and needles, and some offensive odors should be expected around the unit (HCWH, 2001). The huge initial and running cost could be a huge put-off for the application of such a technology in developing countries. Other non-incineration technologies applying high temperatures, heat and steam are macrowaves and hydroclaves, rotoclaves, reverse polymerization which applies high intensity microwave energy and depolymerization using heat and high pressure.

2.3.4. The use of chemicals

Chemical disinfectants such as dissolved chlorine dioxide have been used for disinfecting clinical equipment such as scalpel blades and scapulars for some time, although their application to large volumes of infectious clinical wastes generated by hospitals and laboratories is more recent (Spurgin and Spurgin, 1990). Other chemicals in similar application include sodium hypochlorite (bleach), peracetic acid and dry inorganic chemicals. Chemical disinfection is more suitable for liquid waste according to the U.S.EPA, since doubts still hover over its application for solid and other pathological clinical waste (OTA, 1988; Research Triangle Institute, 1989). Overall, chemical disinfection of solid clinical waste often require shredding, grinding or mixing to increase exposure to the disinfectant, while liquid systems may go through a dewatering section to remove and recycle the disinfectant. Properties such as temperature, pH and the possible presence of other compounds, which can have negative effects on the effectiveness of the chemical agent in particular, are important to inactivate pathogens in the clinical waste stream (Diaz et al, 2005). Additional factors to be considered according to the U.S. Congress Office of Technology Assessment (OTA, 1990) include the types and biology of microorganisms in the wastes, degree of contamination, type of disinfectant, quantity and concentration, contact time, and mixing requirements. A report by the Research Triangle Institute to the U.S.EPA stated that chemical disinfection is easy to use, with little training once the proper operating parameters such as the flow rates for water and chlorine solutions have been established (Research Triangle Institute, 1989).

The efficiency of chemical disinfection provokes skepticism, and thus can only be proven through the application of test pathogens and monitoring on a periodic basis using appropriate indicators in order for the system to be adopted and used on a routine basis. Consistent with reports by the Research Triangle Institute (1989), disinfection with bleach is effective against clinical wastes contaminated with vegetable bacteria and viruses, but less effective against spore-forming bacteria. The same report noted that no standard protocol has been developed to evaluate the efficiency of chemical disinfectants on infectious solid clinical waste.

2.3.5. The use of landfills

The use of landfills remains the most popular method for disposing clinical waste in both developed and developing countries. Diaz et al (2005) makes a distinction between controlled

landfills and sanitary landfills. According to the authors, a controlled landfill is a restricted land disposal facility sited according to hydrological conditions, and in which there is basic record keeping and when full is ultimately covered with vegetation. A sanitary landfill on the other hand is an engineered depression built within the ground with special attention given to geology, hydrology and social characteristics of the area. A sanitary landfill is additionally lined with either natural or artificial synthetic material to prevent permeability. To put it in perspective, a sanitary landfill is like a bathtub in the ground. Potential build-up of methane is monitored in a sanitary landfill, and in some cases it is piped out for alternative uses. A sanitary landfill is also monitored against leachate seeping in to the ground. The leachate is usually extracted from the bottom via pipes and treated before safe disposal. Ground water around a sanitary landfill is constantly monitored and there is a comprehensive plan for closure and post closure.

In the absence of controlled and sanitary landfills, medical establishments, according to Pruss et al (1999) can prepare a small burial pit in a restricted area purposely for disposing only infectious clinical waste. These types of landfills are common within the premises of hospitals in developing countries and are most of the time unfortunately not restricted. The depth of such a pit according to Pruss et al (1999) should reach 2 m deep and the bottom should at least be 1.5 m away from ground water level. Diaz et al (2005) add that such a pit should reach approximately 2 m wide and if possible be lined with compacted clay or any other material of low permeability. The sides over-board the opening of the pit should be elevated to reduce surface water flowing in to it. Pruss et al (1999) suggest that the pit should be filled to a maximum of 1 – 1.5 m and then the pit should be covered with a soil and/ or lime layer, and where there is an outbreak of an especially virulent infection (such as Ebola virus), both lime and soil be used to cover the pit.

2.4. By-products and environmental releases from clinical waste incineration

Despite the numerous alternative non-burn technologies, Hyland (1993) wrote that incineration has remained a popular treatment technology for clinical waste. Attributable reasons include putrefaction prevention of microscopic pathogens, sterilization of pathological and anatomical waste, an estimated 70% and 90% reduction in mass and volume respectively and in some cases recovery of heat and energy (Hyland, 1993; Williams, 1994). Williams (1994) went further to state that the principal by-products of clinical waste incineration are bottom ash, fly ash and gaseous emissions, and depending on the standard and operating conditions of the

unit, these by-products carry with them diversity of pollutants formed or redistributed during the incineration process (Allsopp et al, 2001). Hence such by-products will require further treatment and containment to curb any potential harm to the environment and public health.

2.4.1. Bottom ash and fly ash

A major problem in operating incinerators, according to Shen et al (2010), is the management and containment of its solid by-products, notably bottom ash and fly ash. Bottom ash represents about 75-90% of the total ash content generated by clinical waste incinerators (Williams, 1994) while fly ash, depending on the APCDs, constitute about 2-3% (Chang and Wey, 2006). Many international literature references, according to Gidarakos et al (2009), either characterize bottom ash as dangerous, not dangerous or inert, all in an effort to justify a projected management and disposal method. The Council of the European Union in 2003 included bottom ash in its list of dangerous materials; a decision which eventually increased public apprehension about its safety, and attracts scientific interest and research on its chemical content and potential impact on public health and the environment. Fly ash on the other hand attracts less public apprehension, probably, due to its limited amount, compared with bottom ash, and less visibility.

2.4.2. Inorganic releases

Heavy (or trace) metals are emitted from all types of incinerators and many are known to be toxic at low concentrations and some are persistent and bio-accumulative (Singh and Prakash, 2007). According to Williams (1994) heavy metals constitute <1.5% of the total chemical and mineral content in bottom ash. Other pollutants which might be present include mineral oxides and various organic compounds. In contrast, fly ash is composed of fine particles that rise with the flue gas and contains substantial amounts of SiO₂ and CaO, including heavy metals and organic substances which may vary from trace amounts to several percent (NRC, 2006; U.S.EPA, 2007). Using inductively coupled plasma-optical emission spectroscopy and X-ray fluorescence spectroscopy, Zhao et al (2010) showed that bottom ash from a typical clinical waste incinerator was composed of SiO₂ (26.1%), CaO (30.5%) and Al₂O₃ (10.0%) and contained large amounts of heavy metals such as Zn, Ti, Ba, Pb, Mn, Cr, Ni and Sn. According to the authors, Ba, Cr, Ni and Sn were present in the residual fraction of the bottom ash whereas Mn, Pb and Zn presented in Fe-Mn oxides fraction, and Cu in organic-matter fraction. Using atomic absorption spectrophotometer Racho and Jindal (2004) reported concentrations of Pb,

Ag, Fe and Zn at 765.3, 327.9, 314,121.2, and 18,710.7 mg/kg, respectively in bottom ash from the medical waste incinerator of Ratchasima-Thonburi hospital in the northeastern city of Nakhon Ratchasima in Thailand. The authors reported that the average concentrations of the simulated leachate of Pb, Ag, Fe and Zn at 0.1, 0.1, 0.2 and 0.3 mg/L, respectively, were well below the limits set by EPA and Thai standards.

In studying metal leachability, heavy metals, PAHs and PCBs in fly ash and bottom ashes of a clinical waste incinerator facility, Valavanidis et al (2008) reported the presence of Pb, Cr, Cu, Cd, Ni, Mn, Zn and other lithophilic metals such as Fe, Mg, Ba, Al, Ca, K and Na in both fly and bottom ashes. According to the authors, the concentration of toxic heavy metals in the fly ash were in decreasing order of $Zn > Cu > Ni > Cr > Pb > Cd$. Process operating parameters of the incinerator such as temperature, gas composition, residence time and the presence of reactive compounds such as chlorine, sulfur, or amino silicate can be used to explain such a trend (Sukandar et al, 2006). Other studies such as Bo et al (2009), Tan and Xiao (2010) and Jin et al (2010) have reported concentrations of heavy metals and other inorganic oxides in ash from clinical waste incinerators.

The National Research Council identified Cd, Pb, Hg, Cr and As as the toxic metals mostly associated with clinical waste incineration and further gave detailed descriptions of their toxicity and associated health effects in humans (NRC, 2000). With a huge proportion of bottom ash going in to landfills, Allsopp et al, (2001) and Sawell et al (1988) identified sub-soil contamination and leaching of heavy metals in to either surface or ground water as the main cause for concern, and according to the authors that depends on the species of the metal, pH of the leaching medium and the particle size of the ash. To therefore curb all potential contamination, bottom ash needs to either be immobilized in cement before disposal or be stored in safe and covered containers and disposed of in a special landfill (Adulla et al, 2001; Filipponi et al, 2003).

2.4.3. Organic releases

Bottom ash from clinical waste incinerators is also known to contain organic compounds such as PCBs, PCDD/Fs and PAHs. Anecdotal evidence supports the fact that the amount of chlorine-containing items in the waste stream fed in to the incinerator is the main cause for the release of organic compounds, especially PCDD/Fs. However, according to Hasselriis (1998), an American Society of Mechanical Engineers study that analyzed all available data with HCl

concentrations entering an APCS and PCDD/F emission found no real correlation in the data set. This adds substance to an earlier conclusion by Rigo and Chandler (1995) that the main factor influencing PCDD/F and other organic compound release is the type of emission control device employed and its operating temperature. The main concern over the release of organic compounds into the environment is centered on the associated health hazards (Williams, 1994). The International Agency for Research on Cancer (IARC) and the U.S.EPA classify organic compounds as ubiquitous, persistent in the environment (they can travel long distances before falling to earth and can accumulate in the food chain), extremely potent and can produce toxic effects in humans at extremely low doses (IARC, 1987; U.S.EPA, 2001). Dioxins and dioxin-like compounds and PAHs exist as complex mixtures (75 PCDDs, 135 PCDFs and 209 PCBs) of various congeners in biological and environmental samples, and such variability of the congeners complicates any thorough risk evaluation process for human, fish and wildlife (Van den Berg et al, 1998). The concept of toxic equivalency factors (TEFs) was developed based on the toxicity of the compounds relative to the most potent congeners, that is, 2,3,7,8- TCDD for dioxins and dioxin-like compounds and B[a]P for PAHs, and introduced to facilitate the risk evaluation process. According to Van den Berg et al (1998), the TEF values in combination with chemical residue data can be used to calculate the toxic equivalent quantity (TEQ) in any environmental samples, including animal tissues. International organizations such as the North Atlantic Treaty Organizations' (NATO) committee on the challenges of the modern society (CCMS) and WHO carry out experiments and regularly bring scientific experts to determine and review TEFs for dioxins, furans and dioxin-like PCBs.

During combustion, organic compounds present in the waste stream are partially cracked to smaller and unstable fragments otherwise known as free radical, which through recombination reactions form more stable PAH compounds (Singh and Prakash, 2007). Using GC-MS SIM mode, Zhao et al (2008) reported levels of PAHs in different types of hospital waste incinerator ashes. They found the mean \sum PAH levels in the ashes to vary widely from 4.16 mg/kg to 198.92 mg/kg and the mean amounts of carcinogenic PAHs such as B[a]P (IARC group 1), cyclopenta[cd] pyrene (IARC group 2A) and B[b]F (IARC 2B) ranged from 0.74 to 96.77 mg/kg. According to the authors, bottom ash was dominated by low molecular weight PAHs (2-3 rings) and medium molecular weight PAHs (4-rings), while the fly ash was abundant with medium and high molecular weight PAHs (5-6 rings). The reason for such variation in molecular weight distribution according to the authors is down to the type of incinerator as some

incinerators affect not only the amount of PAHs, but also the molecular weight distribution pattern. Using high performance liquid chromatography with fluorescence detection, Wheatley and Sadhra (2004) found mean concentrations of 11 PAHs in bottom ash from a clinical waste incinerator to range between 2.8 - 173 μ g/kg. Surprisingly, the authors found no PAHs in the fly ash, probably due to matrix effects resulting from excess lime found in the fly ash. Valavanidis et al (2008) carried out a similar study using HPLC to analyze 17 PAHs in bottom ash and fly ash from a clinical waste incinerator. They reported the concentrations in fly ash to be extremely low (detection limit \leq 5.0 mg/kg), with only B[b]F and B[a]P occurring at concentrations of 32 mg/kg and 28 mg/kg respectively while in bottom ash, the concentrations ranged between 10-120 mg/kg. It is worthy to note that the Valavanidis results (due to choice of unit of measurement) are 1000 times larger than Wheatley and Sadhra's, despite both using the same technique.

Combustion of organic matter in the presence of chlorine and metals according to Singh and Prakash (2007) has been identified as the primary source of dioxins and furans in to the environment. Labunska et al (2000) state that only relatively few data are available concerning concentrations of dioxins and furans in ash from incinerators burning clinical or hazardous waste. Results from theoretical and inquiring studies indicate that more than 97% of dioxins are present in bottom ash compared with other by-products of incineration such as gaseous emissions (Gidarakos et al, 2009). Hagenmaier (1987) raised scientific curiosity in this area by reporting levels of PCDD/Fs in fly ash collected from a clinical waste incinerator in Germany to be 2 orders of magnitudes higher than the levels detected in fly ash from municipal waste incinerators. Gidarakos et al (2009) used GC-HRMS to investigate the presence of dioxins and furans in bottom ash from a clinical waste incinerator sampled in winter, spring, summer and autumn. In the first season PCDD/F concentration in the bottom ash was 954 pg TEQ/g (NATO/CCMS) and 1160 pg TEQ/g (WHO1988, humans). In the second, third and fourth seasons, the results were 16,790 pg TEQ/g (NATO/CCMS), 19,710 pg TEQ/g (WHO1988, humans); 1485 pg TEQ/g (NATO/CCMS), 1624 pg TEQ/g (WHO1988, humans) and 8,595 pg TEQ/g (NATO/CCMS), 9,333 pg TEQ/g (WHO1988, humans) respectively. Thacker et al (*unpublished*) reported TEQ values of 12.06 pg TEQ/g for PCDD/Fs in bottom ash, and concluded that clinical waste incinerators are among the main high releasers of the toxic congeners of PCDD/Fs.

Chen et al (2008) found PCDD/F I-TEQ levels in fly ash from a clinical waste incinerator to be 20 times higher than the expected criteria. The unstable combustion in clinical waste incinerators according to the authors leads to more products of incomplete combustion, which might be the precursors for PCDD/F formation. Yan et al (2007) reported levels of PCDD/Fs in fly ash from three different incinerators used for treating clinical waste. The incinerators were a rotary kiln, fluidized bed multi-staged incinerator with activated carbon spray and a simple stoker incinerator without activated carbon spray and the levels were 9547.16 pg TEQ/g, 11371.98 pg TEQ/g and 15619.12 pg TEQ/g respectively. According to the authors, most PCDD/Fs from waste incineration are absorbed in fly ash and depending on the APCDs; about 80% is released in to the environment. Labunska et al (2000) and Valavanidis et al (2008) reported low concentrations of PCBs in bottom ash from clinical/ hazardous waste incinerators, and the former agreed that PCBs can be produced as products of incomplete combustion in incinerators, but however strongly suggest that their presence in the bottom ash residues were from PCBs or PCB-contaminated materials in the incinerator feedstock.

2.4.4. Gaseous emissions

Gaseous emissions from incineration of clinical waste released directly in to the atmosphere according to Williams (1994) have received the most attention from the public, environmental campaigners and legislators due to purported risks to public health. Emissions of most concern include total PM, acidic gases such as hydrogen chloride, hydrogen fluoride, and sulfur dioxide, various organics and metals, CO, NO_x and other materials such as cytotoxins, pathogens and radioactive diagnostic materials.

Incomplete combustion of organics in the waste stream and the entrainment of non-combustible ash, due to turbulent movement of combustible gases according to McCormack et al (1989) can lead to the formation of PM. PM can therefore exist as aerosols or as solids containing heavy metals and organics and trace acids and emissions of PM can vary widely depending upon the type of incinerator, operation parameters and waste type (U.S.EPA, 1988). Clinical waste incinerators with controlled air chambers reportedly produce less PM because of their inherently low gas velocity which results to low gas turbulence, while rotary kilns on the hand produce high amounts of PM due to high turbulent combustion caused by the rotation.

The formation of NO_x, that is, nitric oxide and nitrogen dioxide is understandably linked to the amount of nitrogen compounds in the fuel, air-to-fuel ratio and temperature of the flame

(N.J.SDEP, 1989). The NO_x are either formed when the chemically bound nitrogen in the fuel is oxidized or during the reaction between molecular nitrogen and oxygen in the combustion air. Carbon monoxide on the other hand is a product of incomplete combustion and its formation and subsequent release in to the environment can be linked to insufficient oxygen in the combustion chamber, turbulence and residence time. The amount of chlorine and sulfur in the waste; according to several theories, is used to explain the formation of HCl and SO₂ in flue gas. Chlorine and sulfur are chemically bound within most materials that constitute clinical waste and they are subsequently oxidized to HCl and SO₂ during combustion (U.S.EPA, 1988).

Partial combustion of organic contents in waste streams can either lead to the formation of low molecular weight hydrocarbons such as methane and ethane or in some cases the formation of high molecular weight hydrocarbons such as dioxins and furans. Emissions of PCDD/Fs were investigated in stack flue gases of four clinical waste incinerators and ten municipal solid waste incinerators (MSWI) by Lee et al (2003). The mean PCDD/F concentration in the clinical waste incinerator was 210 times of magnitude higher than that of the MSWI. According to the authors, the fact that the clinical waste incinerators were equipped with low stacks and located in proximity of residential communities could lead to significant environmental exposures. Alvim Ferraz and Afonso (2003a) found that, depending on the composition of the waste, the dioxin concentration in combustion gas from a clinical waste incinerator was 93 to 710 times higher than the legal limit in Portugal. Similar high levels of dioxins were reported in stack emissions from clinical waste incinerators by Coutinho et al (2006) and Sbrilli et al (2003). Alvim Ferraz and Alfonso (2003b) summed it all up, based on their study of emission factors for PM and heavy metals, that appropriate devices must be used to control atmospheric pollutants from clinical waste incinerators since such emissions always surpass all legal limits and eventually bring risks to patients, hospital workers and the general public.

2.5. Health impacts of clinical waste

Protecting health care workers (HCWs) in developing countries, where even the basics of medical care are difficult to provide and where the protection of HCWs does not seem to be among the priorities of policies, is a formidable challenge (Sagoe-Moses et al, 2001). Together with the HCWs, individuals such as children outside the health care environment, who either handle such waste or are exposed to it as a consequence of careless management, further

compound the challenge. Pruss et al (1999) listed the main risk groups (within the health care environment) to include medical doctors, nurses, health-care auxiliaries, and hospital maintenance personnel; patients in health-care establishments or receiving home care; visitors to health-care establishments; workers in support services allied to health-care establishments, such as laundries, waste handling, and transportation; workers in waste disposal facilities (such as landfills or incinerators), including scavengers.

Infectious components in clinical waste such as contaminated sharps and syringes pose the biggest health risks due to potentials for direct exposure to pathogens in blood and other fluid from patients through percutaneous injuries (PI), abrasion and a cut in the skin. Pruss-Ustun et al (2005) estimated that more than three million HCWs experience the stressful event of a PI with a contaminated sharp object each year. Evidence from epidemiological studies indicate that a person who experiences a needle stick injury from a needle used on an infected source patient has risks of 30%, 1.8%, and 0.3% respectively of becoming infected with HBV, HCV and HIV (IHCWS, 2008). Other routes of exposure are through the mucous membranes, inhalation and ingestion (Franka et al, 2009; Pruss et al, 1999). The particular concern about HIV, HBV and HCV is because of the high prevalence of these pathogens, especially in poorer regions of the world, supplemented by strong evidence of transmission via clinical waste (Sagoe-Moses et al, 2001; Pruss et al, 1999). HBV and HCV, including the Lassa and Ebola viruses for example, are endemic in sub-Saharan Africa (Sagoe-Moses et al, 2001).

In a study by Shiao et al (2002), of the 7550 needle stick and sharp injuries reported by 8645 HCWs, 66.7% involved a contaminated hollow-bore needle. In the same study, 1805 blood samples from the HCWs were tested and 16.7% were seropositive for hepatitis B surface antigen, 12.7% were positive for anti-HCV and 0.8% was positive for anti-HIV. The authors estimated, based on their data that 308 to 924 HCWs were at risk for contracting HBV; 334 to 836 were at risk for contracting HCV; and, at the most, 2 were at risk for contracting HIV. Jahan (2005) identified 73 injuries from needles and other sharp objects in a retrospective survey of all self-reported documents in Buraidah Central Hospital, Saudi Arabia. According to the author, nurses, physicians, technicians and non-clinical support staff were involved in 66%, 19%, 10% and 5.5% of the instances respectively. Most of the injuries, according to the author, occurred during recapping of used needles (29%); during surgery (19%); by collision with sharps (14%); disposal related (11%) and as well as through concealed sharps (5%) while handling linens or trash containing improperly disposed needles.

Berger et al (2000) identified that the risk of occupationally acquired infection with hepatitis B and hepatitis C among HCWs is as a result of the frequency of needle stick injuries with patient blood contact, the prevalence of patient virus carriers, the probability of transmission and the immune status of the personnel, in the case of HBV mainly the vaccination rate. In a study of occupational exposure to needle stick injuries and hepatitis B vaccination coverage among HCWs in Egypt, Talaat et al (2003) reported that of the 1485 HCWs interviewed, 529 (35.6%) were exposed to at least 1 needle stick injury during the past 3 months with an estimated annual number of 4.9 needle sticks per worker. According to the authors, 15.8% of HCWs reported receiving 3 doses of hepatitis B vaccine, with vaccination coverage highest among professional staff (38%) and lowest among housekeeping staff (3.5%). The authors estimated that 24,004 HCV and 8617 HBV infections occur each year in Egypt as a result of occupational exposure in the health care environment. In a similar study in the US, Simard et al (2007) reported that among HCWs at risk, 75% had received 3 or more doses of the hepatitis B vaccine, corresponding to an estimated 2.5 million vaccinated hospital-based HCWs. According to the authors, the coverage levels was 81% among staff physicians and nurses and significantly lower among phlebotomists (71.1%) and nurses' aides and/or other patient care staff (70.9%).

Understanding the epidemiology of needle stick injuries in the target population is important in designing and implementing control measures (Jahan, 2005). Pruss-Ustun et al (2005) suggested that strategies such as education of HCWs on the risks and precautions, reduction of invasive procedures, use of safer devices, and procedure and management of exposures are available to prevent infections due to sharps injuries. According to the authors, efficient surveillance and monitor of occupational health hazards related to blood borne pathogens in the industrialized world help to reduce the risk of transmission. On the other hand, the authors noted that, similar surveillance and monitoring systems are weak and dysfunctional and/ or sometimes completely absent in developing countries.

2.6. Summary of the literature review

Clinical waste management in developing countries was given context in the literature review through the extensive complexity involved in the waste management process. However, an important unanswered question is the extent to which poor clinical waste management contributes to the environmental burden at the local, regional and national levels in these

countries. Reliable data on the amount of clinical waste generated by healthcare establishments was identified as an important component for a successful clinical waste management effort. So far, estimates are only available from public healthcare establishments, leaving a cloud of uncertainty over the amounts generated in private healthcare establishments. Studies emphasized efficient clinical waste management as a relevant issue from concept to practice but failed to clearly identify the roles of each of the partners involved in the process; from top government agencies such as Ministries of Health to regional delegations of health and healthcare establishments. Additionally, the role of sub groups such as nurses, doctors, waste pickers and others within the healthcare establishment in the clinical waste management process still remain unclear.

A well structured segregation technique was identified in lots of papers as imperative in reducing the amount of clinical waste generated, deciding on the method to discard it and the efficiency of the whole management process. In fact, some of the authors mention that a properly implemented and well functioning segregation initiative will reduce the amount of infectious or hazardous waste to be discarded by as much as 80% of what is discarded without such measures. The question that comes to mind is how much of the waste is currently incinerated, dumped in open landfills or discarded together with municipal waste. Different types of advanced and environmentally friendly technologies (combustion and non-combustion) for treating clinical waste were extensively covered in the literature review. How these technologies; which by the way are novel and costly, can be transferred, operated and properly maintained in developing countries is still in contention. With obvious threats from emerging contaminants such as pharmaceuticals, how liquid waste from healthcare establishments in developing countries is treated or discarded remains a major question.

Numerous studies identified the types of pollutants that can be potentially released from on-site sub-standard incineration of clinical waste. These were heavy metals and organics such as dioxins and furans, PAHs and PCBs. However, the extent to which these pollutants from sub-standard clinical waste incinerators (single or collective units) alter baseline levels in different environmental media is still uncertain. This uncertainty further compounds human health risk assessment efforts for emissions from the activity. Health hazards of clinical waste in the occupational environment were well documented in the literature review. Doubts over the health issues (for example skin, respiratory and intestinal infections) of vulnerable populations such as children in the vicinity of clinical waste treatment and disposal sites beg for clarity.

II. AIMS OF THE STUDY

This thesis examined environmental exposure and public health impacts from improper management (treatment and disposal) of clinical waste in Cameroon. Different techniques were used to assess generation, segregation, transportation, temporal storage and disposal of clinical waste. With almost complete absence of thorough segregation techniques in clinical establishments, and coupled with the fact that standard incineration units (as a suitable technique for treating the waste) are lacking, the combustion of plastics rich in polyvinyl chloride and other materials in the clinical waste stream result in the presence of pollutants such as toxic metals, PAHs, dioxins and dioxin-like compounds in the gaseous emissions and solid by-products such as bottom ash. Exposure to these pollutants can leave acute and possibly chronic health effects in the population. A scenario like the aforementioned ultimately begs for the need to assess potential environmental exposures, which can contribute substantially to human health risk assessment efforts and effectively emphasize and communicate the position of poor clinical waste treatment and disposal within the spectrum of environmental risks and public health.

Specific aims:

1. Investigate the entire pathway of clinical waste management in Cameroon. The investigation process will evaluate:
 - a) How clinical waste is collected and transported.
 - b) How clinical waste is temporally stored, treated and/ or disposed.
 - c) The knowledge, attitudes and practices of hospital workers towards clinical waste management and its potential environmental and public health effects.
2. Carryout a comprehensive assessment of three randomly selected clinical waste incinerators in Cameroon.
 - a) Evaluate design, construction, operation and maintenance of the incinerators.
 - b) What are the risks from these types of incinerators?
 - c) Identify the type of waste fed in to the incinerators.
3. Analyze levels of pollutants in bottom ash from clinical waste incinerators.
 - a) What is the potential for exposure and contamination?
4. Assess morbidity in children (≤ 10 years) within the vicinity of a poor clinical waste treatment and disposal site.
5. Develop recommendations for a national policy for clinical waste management for Cameroon through a prospective health impact assessment.

Research questions:

1. What is the magnitude of the clinical waste problem in healthcare establishments in Cameroon?
2. What is the contribution of clinical waste management to the environmental and public health burden in Cameroon?
3. How significant are sub-standard clinical waste incinerators and other disposal options for clinical waste to the health of vulnerable populations within the vicinity of such units?

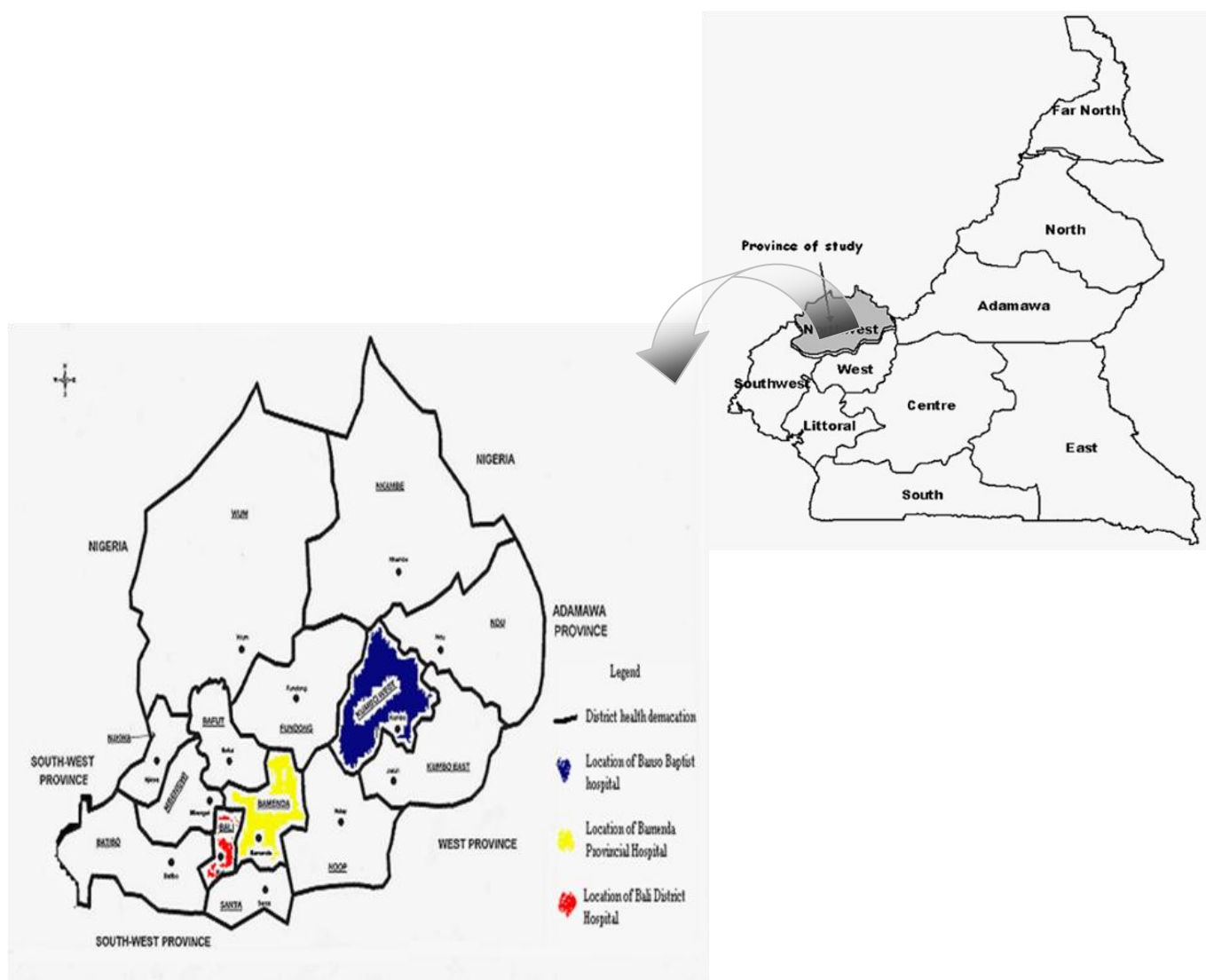
Research hypothesis:

Clinical waste is reported to be of no health consequences to the general population; however, poor treatment and disposal methods can enhance morbidity in vulnerable populations, especially those living within the vicinity of such sites.

4. BACKGROUND OF STUDY AREA

Fieldwork and data collection for this study was carried out in the Northwest region of Cameroon, shown in figure 2. This region was selected because it contains a significant number of establishments offering clinical services; one regional (referral) hospital, 14 divisional hospitals and numerous private (denominational and non-denominational) clinical establishments. Three hospitals (one private and two public) located in three different health districts were selected for the study. The three hospitals were Bansa Baptist Hospital (BBH) which is located in the Kumbo health district, Bamenda Regional Hospital (BRH) which is located in the Bamenda health district and Bali District Hospital (BDH) which is located in the Bali health district.

Figure 2: Map of Cameroon indicating the region of study.



Source: Northwest Regional Delegation for Public Health (NWRDPH, 2005)

The Northwest Region

The city of Bamenda; 366 km from Yaoundé (the national capital) is the capital of the Northwest region of Cameroon. The region has an estimated total population of 2,149,971 inhabitants, with an estimated urban population of 446,000 inhabitants (NIS, 2005). It has a land surface area of 17,300 sq. km (NWRDPH, 2005) with a characteristically undulating terrain. The region is 1500 m above sea level, and has 18 health districts, 176 health areas and 173 integrated health areas (NWRDPH, 2005).

Bamenda Regional Hospital

The Bamenda Regional Hospital has an estimated bed capacity of over 200 beds (NWRDPH, 2005). Figures at the hospital estimate daily patient inflow/ outflow somewhere between 250 and 300. The hospital offers daily in/out-patient services, major and minor surgeries, post and ante natal services to the population of the regional capital city and its environs. Numerous specialist medical services are on offer at the hospital. Examples include: chemotherapy, ophthalmology, neurology, gynecology and obstetrics, reanimation are offered at the hospital. The hospital runs a modern laboratory, blood bank, HIV screening and counseling unit and a morgue.

Bali District Hospital

The Bali District Hospital has a bed capacity of 100, but at the time of data collection for this study, only 69 were functional. The hospital offers services such as daily out/ in-patient consultations and drug prescriptions, minor surgery, ante and post natal care and emergency services to the population of the Bali health district area. Estimated figures show that the hospital receives 300 new patients per month and a joint 450 old and new patients on monthly bases. The hospital runs a small clinical laboratory and a morgue. Through the district medical officer, it supervises the health and integrated health centers within its district. The district hospital refers cases requiring more specialist services to the lone regional (referral) hospital in Bamenda.

Banso Baptist Hospital

The Banso Baptist Hospital is denominationally affiliated with the Cameroon Baptist Convention, and is under the supervision of the Baptist Health Board. The hospital has an estimated bed capacity of over 300 beds and offers services similar to that offered at the Bamenda regional hospital with the morgue as an exception.

Study populations:

a) Healthcare workers

Employees at the three selected hospitals in the Northwest Region of Cameroon constituted this group. They were distributed as follows; 160 from Bali District Hospital, more than 300 from the Bamenda Regional Hospital and more than 400 from the Banso Baptist Hospital. Since not all of the employees deal with clinical waste, only those workers whose jobs lead to the generation or disposal of clinical waste were finally sampled. These involved doctors and nurses of all categories, midwives, laboratory technicians, waste pickers and incinerator operators. Those not considered to be directly involved with clinical waste such as clerical workers (secretaries) and those in the maintenance unit such as motor mechanics were excluded from the final study population. All respondents were issued the same questionnaire irrespective of job experience and level of education.

b) Children

Two cohorts of children less than or equal to the age of 10 years were selected. The first cohort, considered as the exposed group, was made-up of 10 children- 6 males and 4 females. Their average age was 6.5 years. Exposure constituted living within the vicinity and having unrestricted access to a clinical waste treatment and disposal site. Sub-standard incineration and open fires, open landfills and surface dumps are all methods interchangeably and sometimes jointly used at the site. Distance to and from the disposal site was not taken into consideration as all the children had unrestricted access to the site.

The unexposed cohort was also made-up of 10 children; 4 males and 6 females, with an average age of 7 years. The children in this cohort live in a separate neighborhood, with an estimated 20 km from the exposed. Such a distance was deemed

sufficient enough to ensure that the children do not play together as a control for cross-contamination. This neighborhood had no hospitals or clinics and no waste dump site. Children were selected because of their fragility, developing immune systems and for the fact that they often play at such sites. Living conditions in both the exposed and unexposed groups were similar.

Mozambique setting:

Ash samples were collected from an engineered clinical waste incinerator (EI) and an open fire pit (OFP) located at the rear premises of the Jose Macamo general hospital in Maputo. The hospital has a capacity of 400 beds, with a 95% occupancy rate. A total number of 1050 deliveries and 250 surgeries are respectively performed at the hospital each month. The hospital generates an estimated 800 kg of waste per day.

a) Engineered clinical waste incinerator:

This is a small 50 kg/hr unit (though an average of 70 kg/hr is reported). The incinerator is securely located thus preventing access by children, scavengers and stray animals. It was first put in to service on January 19th 2009. It has two burn chambers; a primary chamber where temperatures can reach up to 500 °C and a secondary chamber where temperatures can reach up to 800 °C. Propane gas is used for start-up and then the entire combustion process runs on diesel fuel. An automated fan system regulates the amount of air (oxygen) that gets in to the burn chambers. When start-up is initiated, the unit takes about 15 minutes to reach optimum temperature, first in the secondary chamber and then in the primary chamber. A hydraulic loader is used to feed waste in to the primary chamber and combustion take place on an iron grate. The iron grate allows ash to collect in a separate compartment located at the bottom of the incinerator. Gaseous emissions leave the secondary chamber through a chimney. Air pollution control devices are absent in the unit. The secondary chamber fulfils this role by burning the gases at a higher temperature. Bottom ash is periodically removed from the unit and disposed in adjacent fields where food crops such as vegetables are grown. The unit is meant to treat segregated infectious medical waste; however bottom ash from the unit contained items such as soft drink cans and broken bottles.

b) Open fire pit:

The OFP is located about 50 m west from the EI. The site is surrounded by thick grass that gets to knee-level height. The area is unprotected, leading to uncontrolled access by all- children, scavengers and stray animals. Access to the area is through a footpath overwhelmed with the smell of human waste. All kinds of wastes, from infectious wastes such as vials and contaminated syringes, to card boards and plastics, and general household wastes are dumped at the site without supervision. Fire at the site is set-up by setting the cardboards in to flame, which then spreads to the other items around it. Columns of black smoke start escaping from the site in to the atmosphere about 2 minutes after the flame is initiated and the intensity reduces as the fire wears out. Ash generated during burning is abandoned at the site, where it mixes with surrounding soil which is sometimes used for farming. Since burning is unsupervised, potentially infectious vials, needles and syringes and other items could be seen lying around the site.

5. METHODOLOGY

Both qualitative and quantitative methods were used to generate data for the study.

Qualitative methods were used to evaluate and understand the clinical waste management process and to identify the bottle-neck issues embedded within the process. Observation and interpretation of texts, including in-formal discussions were the major qualitative methods adopted. Quantitative methods adopted were the use of questionnaires and laboratory analytical instruments such as inductively coupled plasma-mass spectrometry (ICP-MS) and gas chromatography-mass spectrometry (GC-MS) for the analysis of heavy metals and organic compounds respectively in the bottom ash. Chemical analysis was performed to ascertain the potential for environmental exposure and contamination and not to establish a strong causal link with health outcome.

5.1. Theoretical framework for HIA

Health issues in new policies, projects and programs prior to HIA received little attention. Thanks to this relatively new concept, this is not the case today as new policies and projects (in many countries which have adopted the concept and practice) undergo rigorous HIA. Several other nations are investing on programs of capacity building to ensure that there is adequate organizational and workforce capacity to undertake HIA (Harris-Roxas and Harris, 2010). The definition of HIA has evolved a lot since it was established. In 1997, Ratner et al (1997) define it as any combination of procedures or methods by which a proposed policy or program may be judged as to the effects it may have on the health of a population. Quigley et al (2006) saw it as a combination of procedures, methods and tools that systematically judge the potential, and sometimes unintended, effects of a policy, plan, program or project on the health of a population and the distribution of those effects within the population. One common theme in HIA that cuts across the definitions is the evaluation of the impacts of determinants of health on health and how these impacts are distributed across the population.

The purpose of this HIA is seen within the context in which it is performed- the identification and assessment of risk factors, associated hazards and the development of evidenced-based recommendations for a clinical waste management policy for Cameroon. Health is defined in the process as a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity (Preamble to the Constitution of the WHO, 1946). Ratner et al (1997) identified five principal stages of HIA; screening, scoping, risk assessment, decision making and implementation and monitoring. The fact that HIA is today practiced at

international and regional levels (Harris-Roxas and Harris, 2010), has resulted in practitioners breaking the aforementioned five principal stages in to sub steps or even labeling them differently.

The screening phase involves deciding on the policy and if it is HIA worthy and determining the potential health effects as a result of the policy. Since no policy existed at the time this study was commissioned, no screening tool was used. Decision to continue with the HIA was based on the following two reasons:

- It was observed that clinical establishments and their waste treatment and disposal sites are located within communities. Consequently, emissions and contaminants from such sites can directly or indirectly affect the health of that community.
- Poor clinical waste management is a cause of popular concern as it can contribute significant occupational health risks and eventually threaten public health.

Scoping was carried out in two phases; firstly, stakeholders were identified through consultations with health officials at the regional delegation for public health in the Northwest region of Cameroon. Consultations were also held with managers of non-governmental organizations with interest in waste management, and members of local hospital management committees. After the consultations, 15 people were selected with diverse backgrounds such as medical doctors, infection control nurses, waste auditor, incinerator operator and waste picker. The second phase involved search of evidence to support the HIA process and the identification of risk factors associated with poor clinical waste management. This was done through emailing questionnaires to the 15 stakeholders. A concise literature review was conducted on the purported health impacts of poor clinical waste disposal to facilitate risk appraisal as part of the HIA process. Searches were performed in on-line data bases such as PubMed, Biosis, Ingenta, Cochrane Controlled Trials Register and ScienceDirect. The evaluation and reporting part was meant to assess how the whole HIA process was conducted and the extent to which its recommendations could be integrated in to the prospective clinical waste management policy for Cameroon. This whole assessment process was conducted by the authors with assistance from colleagues at the Unit for Health Promotion Research at the University of Southern Denmark.

5.2. Questionnaires

Three different questionnaires were designed and used for data collection during the course of this project. A series of group discussions held at the Unit for Health Promotion

Research of the University of Southern Denmark facilitated the development of the questions and the questionnaires were all pre-tested for content and clarity at the said unit. The three questionnaires were:

1. Clinical waste management questionnaire which was directed to hospital workers and the questions focused on awareness of cradle-to-grave management of clinical waste in the selected hospitals, including impacts on environment and public health.
2. A disease frequency questionnaire which was directed to the parents or legal guardians of children ≤ 10 years living close to a clinical waste treatment and disposal site.
3. An HIA questionnaire which was directed to stakeholders involved in the process of clinical waste management in the region.

During discussions at the research unit mentioned above, preliminary questions for the clinical waste management questionnaire were supplemented by questions from a similar questionnaire used by Akter (2000). Some of Akter's questions were modified to make them more relevant and understandable to our study population.

On the bases that limited research has been done on the health hazards associated with living next to where clinical waste is treated, disposed and dumped, questions in the disease frequency questionnaire were devised to generate data on how often children in neighborhood communities to such sites suffer from respiratory, intestinal and skin infections. We sort to examine the exposure (through a simple conceptual model for exposure assessment), and estimate morbidity (as relative risk estimates) and identify points for intervention. Children were preferred because of their fragility, developing immune systems and for the fact that they often play at such sites. Due to the nature of the population being studied, the questionnaire was filled-out by a parent or legal guardian. Observations were recorded in the first week of each month from May to September 2008. The cases reported were not confirmed through medical examination.

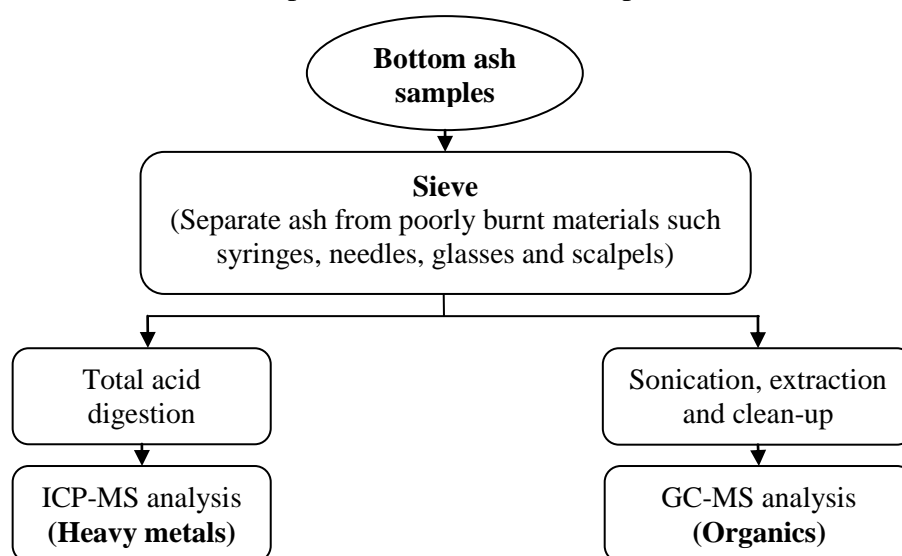
The HIA questionnaire was divided in to a background which explained its purpose, the situation of clinical waste management in Cameroon and the need for a policy, the steering group of the scoping exercise and the expected outcome from the entire process including the value of HIA when applied during the early stages of a policy development process. Part one of the questionnaire defined HIA, listed objectives and the holistic model of HIA. Part 2 focused on the personal information of the respondent such as place of work, position and duration of employment. Part three was made up of 16 open and close questions for the respondent.

Empirical field observation, informal interviews, filming and photo shots were other techniques used on the field.

5.3. Sample collection and analysis

- Bottom ash samples were collected from the incinerators of the three selected hospitals in the Northwest region of Cameroon. The samples were collected early in the morning when the operator was preparing the unit for start-up. Plastic spoons were used to collect the samples which were then poured and securely locked in to plastic containers bought from the local hospital pharmacies. Different plastic spoons were used at different sampling sites to prevent contamination. The samples were flown to Denmark and frozen at 30°C until analysis for heavy metals was done at Aalborg University Esbjerg. For logistics reasons, these samples were not analyzed for organics.
- Bottom ash from similar incinerators in Mozambique was collected with scalpels and stored in zip-lock polyethylene bags. The samples were flown to University of Michigan and stored at 30°C until analysis was done for organics. Figure 3 shows the methodology flow chart for analysis of heavy metals and organic compounds in the bottom ash samples. Details on quality assurance and sample analysis are in the corresponding article located at the back of this dissertation (hard copies only).

Figure 3: Methodology flow chart for analysis of heavy metals and organic compounds in bottom ash samples



5.4. Data analyses

Detailed description and vivid presentation of new understanding was used in qualitative analysis. Two-by-two descriptive tables were used to demonstrate the characteristics of the pilot locations and to illustrate hospital workers' awareness of clinical waste and its associated environmental and public health impacts. Levels of awareness were reported in percentages at 95% confidence intervals. Two-by-two descriptive tables were additionally used to illustrate the variability in responses from the different stakeholders during the HIA process. Quantitative analysis was facilitated through the use of familiar statistical packages in which relevant techniques were adopted. Two-by-two epidemiological table was used to analyze data generated by the disease frequency questionnaire. Risk ratio (95% confidence interval) and risk differences were compared between the groups, including the total risk and the risk in each of the group. Relevant multivariate statistical methods and bar charts were used to analyze pollutants in the bottom ash from the clinical waste incinerators.

5.5. Ethical approval

Ethical approval was obtained from the Regional Delegation for Public Health in the Northwest region of Cameroon. The Institutional and Review Committees of both the Regional Hospital for the Northwest and the Bansa Baptist Hospital also approved all the studies. Informed consent was additionally obtained from the parents and/ or legal guardians of the children who were involved in the morbidity study.

6 RESULTS

The main results summarized in this section are from the six original research papers developed during the course of the study. These include the process of clinical waste management in Cameroon, hospital workers' awareness of environmental and public health impacts of poor clinical waste disposal and the standard of clinical waste incinerators in selected hospitals. Results of the concentration of trace metals and organic compounds in bottom ash from clinical waste incinerators in Cameroon and Mozambique are also summarized. Findings from an exploratory morbidity study and from an HIA prospectively conducted to establish needs and prerequisites for a clinical waste management policy for Cameroon are also included. Due to some constrains, the reported results do not emphasize a causal inference of high statistical power but add strongly to what is required to bring the sector in conformity with international standards.

6.1. Process of clinical waste management in Cameroon

At the selected hospitals, short comings were observed in relation to waste segregation, collection, transportation, temporal storage, treatment and disposal. At points of generation such as wards, casualty units, operating theaters, laboratory units and consultation rooms of general practitioners, waste is predominantly collected in plastic buckets which either have washed-off labels and/ or does not contain them at all. The buckets were sometimes overfilled and/ or broken as shown in figure four. Some of the containers meant for waste collection were without covers and were sometimes located at hallways and entry/ exit points. This was inappropriate as it restricts free circulation of people and could be potentially run-over, thus spilling its contents and causing unnecessary inconveniences.

Figure 4: A broken clinical waste receptacle in the Northwest region of Cameroon



Syringes, needles and utility gloves were placed in separate containers while others such as blood-soaked swabs, band-aids and convenience pads were placed in others. Transportation of the waste from the points of generation to the temporal storage area differed with the selected hospitals. In one of the hospitals, the waste picker (who doubles as the incinerator operator) goes around with a wheel barrow and empties all the contents of the individual containers in to the wheel barrow and then transports them to the disposal location. At the other hospitals, the waste pickers (who did not operate the incinerators) carried the containers with their bare hands, and sometimes on their heads to the disposal location. This was inappropriate as it exposes the waste carriers to risks of cross-contamination and other unspecified injuries. Some of the selected hospitals lacked a temporal storage area, and as such the waste was immediately disposed in open pits and at unrestricted areas. Those that have a temporal storage area locate it close to the incinerator as shown in figure five so as to facilitate loading in to an incinerator.

Figure 5: Example of a clinical waste temporal storage area in Cameroon



Treatment and disposal options ranged from the use of open landfills, surface dumps and sub-standard incinerators. Tissue (sometimes referred to as anatomical waste) waste is predominantly disposed of in safe (closed) landfills as shown in figure six.

Figure 6: Disposing anatomical waste in a closed landfill in Cameroon



6.2. Awareness of hospital workers

Results of the awareness of hospital workers on aspects of poor clinical waste management as summarized in table one.

Table 1: Awareness of hospital workers on aspects of clinical waste management in Cameroon

Awareness variables	Categories	Results (%)	95 % CI
Concept of clinical waste.	Basic knowledge	57.5	46.2 - 68.7
	Appropriate knowledge	18.8	12.7 - 24.9
	Don't know/ No answer	23.8	16.7 - 30.9
Health impacts of poor clinical waste management.	Adequate knowledge	55	44.2 - 65.8
	Inadequate knowledge	20	17.7 - 32.3
	No answer	25	13.5 - 26.5
Environmental impacts of poor clinical waste management.	Aware	37.5	28.5 - 46.5
	Unaware	62.5	50.9 - 74.1
Policy or guidelines on efficient clinical waste management.	Yes	21.2	14.5 - 27.9
	No	78.8	67.5 - 91.9
Public concerns on the negative impacts of existing management methods.	Yes	31.2	23 - 39.4
	No	68.8	56.7 - 80.9

CI = confidence interval

Concept of clinical waste:

Respondents were asked to provide a definition of clinical waste. Definitions were classified by researchers as “basic” or “appropriate.” Most respondents had a basic knowledge (57.5%) compared to those with an appropriate knowledge (18.8%). Nearly one quarter (23.8%) did not respond to the questions.

Health impacts of poor clinical waste management:

As shown in table 1, 55% of the respondents demonstrated an understanding of the general risks of exposure to clinical waste. They were able to identify some risks such as percutaneous injuries from needles, and possible respiratory infection as a result of emissions from poor incineration facilities. Twenty percent (20%) of the respondents showed inadequate understanding of the general risks to poor clinical waste management. Another 25% of the respondents did not respond to this question.

Environmental impacts of poor clinical waste management:

Respondents were classified as either aware (37.5%) or unaware (62.5%). Those who were aware showed sufficient understanding and identified environmental damage which might result from poor clinical waste management such as soil and water pollution. Most of the

respondents (the unaware group) were incapable of identifying any environmental damage that might result from poorly disposing clinical waste in the environment.

Policy or guideline on efficient clinical waste management:

21.2% of the respondents knew that policies and guidelines exist on the efficient management of clinical waste. Examples of such policies given were those from international organizations such as the WHO. The remaining 78.8% had never heard of a policy or guideline linked to efficient management of clinical waste, at either the national or international level.

Public concerns on the negative impacts of existing management methods:

31.2% of the respondents agreed on complaints or concerns from residents around the hospitals relating to methods of clinical waste disposal. The most frequently reported concerns, according to the respondents, were difficulty breathing during the burning of clinical waste and the foul smell from decomposing tissues. The remaining 68.8% had not heard any concerns from residents close to the disposal sites.

6.3. Standard of clinical waste incinerators in selected hospitals

Three clinical waste incinerators in Cameroon denoted as A, B and C shown in figure seven were evaluated against universal standard norms for site, design and operation parameters. All three incinerators were located on-site, that is, at the rear end of the hospital premises. Incinerator A is predominantly constructed out of corrugated metal sheets while incinerator B and C were built out of a combination of corrugated metal sheets and burnt clay and cement bricks. Start-up and shut-down of the incinerators followed no precise routine while the fuel for combustion varied with each incinerator. Kerosene is poured on to the waste in A and the flame is initiated with a match strike. Incinerator B uses diesel while C uses biomass (chopped wood). The chimney in incinerator B constituted a metal pipe typically used for transporting water and it was clogged at evaluation. The chimneys in A and C were within the height of the roofs of surrounding houses. Design and operational flaws associated with the three incinerators include the absence of online monitoring, waste feed at $> 850^{\circ}\text{C}$, auxiliary burners and APCDs.

Figure 7: Clinical waste incinerators in selected hospitals in Cameroon

Incinerator A



Incinerator B



Incinerator C



6.4. Heavy metals and organic compounds in bottom ash

6.4.1. Heavy metals

ICP-MS analysis quantified Cr, Cu, Fe, Mn, Ni, Pb, Zn, Mg and Ca in bottom ash samples from the three selected clinical waste incinerators, while As, Cd, Co, Sb and Ag were below the detection limit as shown in table three. In incinerator A, calcium had the highest mean concentration of 118250 mg/kg while Pb had the lowest mean concentration of 10 mg/kg. Copper had the lowest mean concentration of 60 mg/kg in incinerator B while Ca had the highest mean concentration of 114090 mg/kg. In incinerator C, calcium had the highest concentration of 178080 mg/kg while copper was lowest with a concentration of 140 mg/kg. Chromium and Ni were below the detection limit in bottom ash samples from incinerator C. The concentration of Pb (230 mg/kg) in incinerator C was noticeably high.

Table 2: Mean and standard deviation for heavy metals in bottom ash samples from three clinical waste incinerators in Cameroon

Heavy metal	Incinerator A		Incinerator B		Incinerator C	
	Mean (mg/kg)	SD	Mean (mg/kg)	SD	Mean (mg/kg)	SD
Cr*	530	330	130	157	BDL	BDL
Cu*	80	11	60	55	140	5
Fe	4900	1959	57 250	48 666	18 540	2150
Mn	100	27	180	194	1640	30
Ni	210	125	70	56	BDL	BDL
Pb*	10	11	90	43	230	31
Zn*	2870	131	5390	755	3790	202
Mg	6190	172	1800	193	10 860	453
Ca	118 250	4340	114 090	44 986	178 080	4786
As*	BDL	BDL	BDL	BDL	BDL	BDL
Cd*	BDL	BDL	BDL	BDL	BDL	BDL
Co	BDL	BDL	BDL	BDL	BDL	BDL
Sb	BDL	BDL	BDL	BDL	BDL	BDL
Ag	BDL	BDL	BDL	BDL	BDL	BDL
TOTAL	133 140	6623	179 060	95 105	213 280	7656
TOTAL (U.S. EPA)	3490	483	5670	1010	4160	237

*U.S. EPA priority metals; BDL = below detection limit; SD = Standard deviation

6.4.2. Organic compounds

6.4.2.1. Polycyclic aromatic hydrocarbons (PAHs)

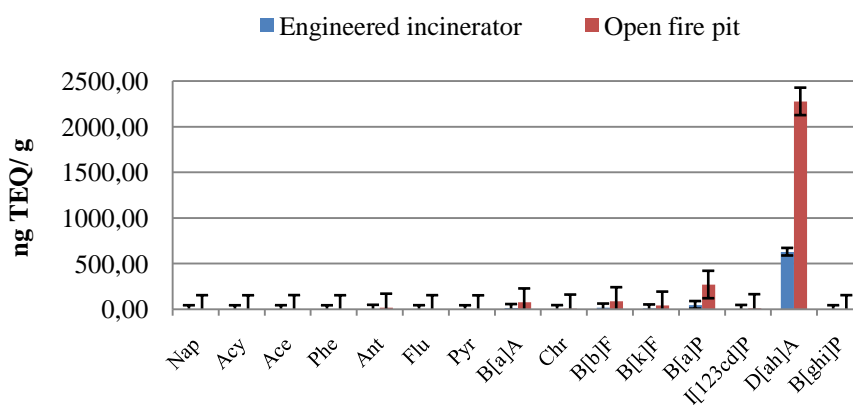
GC-MS analysis quantified 15PAHs above the limit of detection (LOD) in both ash types. The 15PAHs quantified were naphthalene (Nap), acynaphthalene (Acy), acenaphthalene (Ace), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flu), pyrene (Pyr), benzo [a] anthracene (B[a]A), chrysene (Chr), benzo [b] fluoranthene, (B[b]F), benzo [k] fluoranthene (B[k]F), benzo [a] pyrene (B[a]P), indeno [1,2,3-cd] pyrene (I[1,2,3-cd]P), dibenzo [a,h]anthracene (D[a,h]A) and benzo [g,h,i] perylene (B[g,h,i]P). The levels of PAHs differed significantly; very high in OFP and low in EI. Low (2-3 ringed PAHs) and medium (4- ringed PAHs) molecular weight PAHs dominated in both ash types. The levels (ng/g) of the different congeners and corresponding TEQs are shown in table 3.

Table 3: Level and TEQ values for ash samples from an engineered incinerator and open fire pit for treating clinical waste.

	*TEF	Engineered incinerator			Open fire pit		
		Level	TEQ	TEQ	Level	TEQ	TEQ
		ng/g	ng TEQ/ g	%	ng/g	ng TEQ/ g	%
Nap	0.001	394.9	0.39	0.05	1811.5	1.81	0.06
Acy	0.001	256.6	0.26	0.04	977.6	0.98	0.03
Ace	0.001	677.7	0.68	0.09	2587.9	2.59	0.09
Phe	0.001	234.6	0.23	0.03	1122.7	1.12	0.04
Ant	0.01	496.0	4.96	0.68	1829.4	18.29	0.65
Flu	0.001	755.7	0.76	0.10	1760.6	1.76	0.06
Pyr	0.001	121.5	0.12	0.02	435.4	0.44	0.02
B[a]A	0.1	134.0	13.40	1.84	758.6	75.86	2.71
Chr	0.01	167.7	1.68	0.23	851.5	8.51	0.30
B[b]F	0.1	187.4	18.74	2.57	893.6	89.36	3.19
B[k]F	0.1	90.9	9.09	1.25	410.9	41.09	1.47
B[a]P	1	46.2	46.20	6.34	269.1	269.10	9.61
I[123cd]P	0.1	36.4	3.64	0.50	126.9	12.69	0.45
D[ah]A**	5	125.7	628.50	86.19	455.1	2275.50	81.23
B[ghi]P	0.01	58.8	0.59	0.08	215.1	2.15	0.08
	Σ	3784.1	729.24	100	14505.8	2801.25	100

[†]Unitless; **A TEF of 1 appears to be appropriate for high doses but 5 is more applicable to environmental exposures.

Σ TEQ was significantly higher in ash from OFP (2801.25 ng TEQ/ g) compared with ash from EI (729.24 ng TEQ/ g). The range in EI was from 0.12 ng TEQ/ g to 628.50 ng TEQ/g while in OFP, it ranged from 0.44 ng TEQ/ g to 2275.50 ng TEQ/ g. D[a,h]A had the highest TEQ in both ash samples; with the level in OFP more units of magnitude higher than that in EI as shown in figure 8. Statistical analysis (T-test- paired 2-sample for means) showed that the mean difference of 15PAHs was -714.8 (95% CI. -424.9, -1004.7), and the standard deviation (SD) was 523.5. The t-value was -5.29, corresponding to a two-tailed *p* - value of 0.0001 (based on a t distribution with 15 – 1 = 14 degrees of freedom).

Figure 8: Compositional variation in TEQs of 15PAHs in ash samples from an open fire fire pit and an engineered incinerator used for treating clinical waste

6.4.2.2. Dioxin-like (co-planer) polychlorinated biphenyls (PCBs)

The levels of dioxin-like PCBs and their corresponding TEQs are shown in table 4. The total levels in EI and OFP were 13.40 ng/g and 20.22 ng/g respectively. The range in EI was from 0.03 ng/g to 4.92 ng/g, while in OFP, the range was from 0.03 ng/g to 7.29 ng/g. PCB114 and PCB123 were both below the LOD of 0.03 ng/g in both ash types.

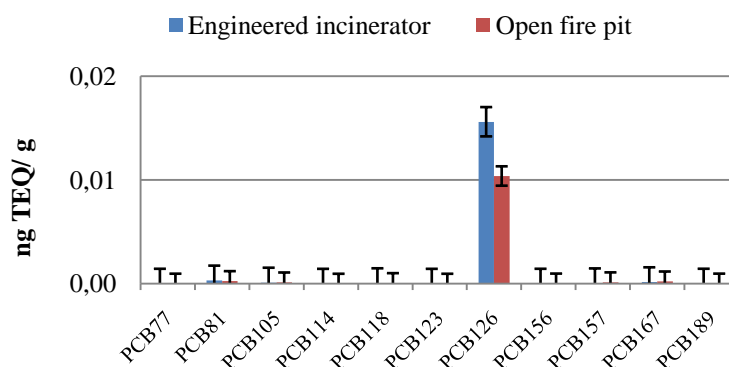
Table 4: Level and TEQ values for dioxin-like PCBs of ash samples from an engineered incinerator and open fire pit for treating clinical waste.

	*TEF	Engineered incinerator			Open fire pit		
		Level ng/g	TEQ ng TEQ/ g	TEQ %	Level ng/g	TEQ ng TEQ/ g	TEQ %
PCB77	0.0001	0.04	0.0000040	0.025	0.10	0.0000098	0.09
PCB81	0.0003	1.03	0.0003099	1.901	0.85	0.0002541	2.27
PCB105	0.00003	3.61	0.0001083	0.664	4.20	0.0001259	1.12
PCB114	0.00003	0.03	0.0000008	0.005	0.03	0.0000008	0.01
PCB118	0.00003	1.70	0.0000511	0.314	2.04	0.0000611	0.55
PCB123	0.00003	0.03	0.0000009	0.006	0.03	0.0000009	0.01
PCB126	0.1	0.16	0.0156000	95.706	0.10	0.0103667	92.56
PCB156	0.00003	0.21	0.0000063	0.039	0.63	0.0000190	0.17
PCB157	0.00003	1.41	0.0000423	0.259	4.50	0.0001350	1.21
PCB167	0.00003	4.92	0.0001475	0.905	7.29	0.0002188	1.95
PCB189	0.00003	0.27	0.0000081	0.050	0.46	0.0000137	0.12
	Σ	13.40	0.016	100	20.22	0.011	100

*Unitless

Σ TEQs for dioxin-like PCBs in EI and OFP were 0.016 ng TEQ/ g and 0.011 ng TEQ/ g respectively. The range in EI was from 0.0000008 ng TEQ/ g to 0.0156000 ng TEQ/ g. In OFP the range was from 0.0000008 ng TEQ/ g to 0.0103667 ng TEQ/ g. The TEQ level for PCB126 was conspicuously higher in both ash samples when compared with the other congeners as shown in figure 9. The mean difference of total dioxin-like PCBs was -0.62 (95% CI. -0.11, -1.35) and the SD = 1.08. The t value was -1.90, corresponding to a two-tailed *p* - value of 0.09, based on a t distribution with $11 - 1 = 10$ degrees of freedom.

Figure 9: Compositional variation in TEQs of dioxin-like PCBs in ash samples from an open fire pit and an engineered incinerator used for treating clinical waste



6.4.2.3. Dioxins and furans (PCDDs and PCDFs)

The levels and TEQs for dioxins and furans are shown in table 5. Three congeners of PCDDs; 1, 2, 3, 7, 8, 9-HxCDD, 1, 2, 3, 4, 6, 7, 8-HpCDD and OcCDD were measured in both ash types. \sum PCDDs in EI and OFP were 54.80 ng/g and 108.65 ng/g respectively. In ash from EI, PCDDs ranged from 0.01 ng/g to 37.60 ng/g, with OcCDD being the most abundant at 36.60 ng/g, while the range in OFP was from 0.01 ng/g to 82.02 ng/g, OcCDD being the most abundant at 82.02 ng/g.

\sum PCDFs in EI and OFP were 2.99 ng/g and 4.55 ng/g respectively. PCDFs in EI ranged from 0.02 ng/g to 1.66 ng/g, while the levels in OFP ranged from 0.02 ng/g to 2.92 ng/g. OcCDF was the most abundant in both EI and OFP, with values of 1.66 ng/g and 2.92 ng/g respectively.

Table 5: Level and TEQ values for dioxins and furans in ash samples from an engineered incinerator and open fire pit for treating medical waste.

	*TEF	Engineered incinerator			Open fire pit		
		Level ng/g	TEQ ng TEQ/ g	TEQ %	Level ng/g	TEQ ng TEQ/ g	TEQ %
Dioxins							
2,3,7,8-TCDD	1	0.04	0.035	12.87	0.03	0.032	8.20
1,2,3,7,8-PeCDD	1	0.02	0.020	7.35	0.02	0.020	5.18
1,2,3,4,7,8-HxCDD	0.1	0.01	0.001	0.37	0.01	0.001	0.26
1,2,3,6,7,8-HxCDD	0.1	0.01	0.001	0.37	0.01	0.001	0.26
1,2,3,7,8,9-HxCDD	0.1	0.36	0.036	13.38	0.47	0.047	12.23
1,2,3,4,6,7,8-HpCDD	0.01	16.75	0.168	61.59	26.09	0.261	67.58
OcCDD	0.0003	37.60	0.011	4.15	82.02	0.025	6.37
	Σ	54.80	0.272	100	108.65	0.386	100
Furans							
2,3,7,8-TCDF	0.1	0.04	0.0035	4.73	0.04	0.0035	3.30
1,2,3,7,8-PeCDF	0.03	0.21	0.0062	8.43	0.36	0.0107	10.07
2,3,4,7,8-PeCDF	0.3	0.02	0.0060	8.11	0.02	0.0060	5.66
1,2,3,4,7,8-HxCDF	0.1	0.02	0.0015	2.03	0.02	0.0018	1.73
1,2,3,6,7,8-HxCDF	0.1	0.02	0.0015	2.03	0.02	0.0018	1.73
2,3,4,6,7,8-HxCDF	0.1	0.26	0.0260	35.14	0.39	0.0393	37.07
1,2,3,7,8,9-HxCDF	0.1	0.23	0.0232	31.35	0.38	0.0380	35.82
1,2,3,4,6,7,8-HpCDF	0.01	0.35	0.0035	4.76	0.20	0.0020	1.90
1,2,3,4,7,8,9-HpCDF	0.01	0.20	0.0020	2.70	0.21	0.0021	1.94
OcCDF	0.0003	1.66	0.0005	0.67	2.92	0.0009	0.83
	Σ	2.99	0.0740	100	4.55	0.1061	100

*Unitless

Total dioxin TEQ level in EI and OFP was 0.272 ng TEQ/ g and 0.386 ng TEQ/ g respectively. 1, 2, 3, 4, 6, 7, 8-HpCDD had the highest TEQ in both ash samples as shown in figure 10. The TEQ was 0.168 ng TEQ/ g (61.59% of total dioxin TEQ) in EI and 0.261 ng TEQ/ g (67.58%) in OFP. The mean difference for total PCDD was -7.69 (95% CI. -23.01, 7.63) and the SD was 16.56. The t value was -1.23, which corresponds to a two tailed p - value of 0.27 (based on a t-distribution of $7 - 1 = 6$ degrees of freedom).

Total furan TEQ level in EI and OFP was 0.074 ng TEQ/ g and 0.160 ng TEQ/ g respectively. 2, 3, 4, 6, 7, 8-HxCDF and 1, 2, 3, 7, 8, 9-HxCDF had the highest TEQ level in both ash samples as shown in figure 11. Both congeners accounted for 66.49% and 72.89% of total PCDF TEQ in EI and OFP respectively. The mean difference for total PCDF was -0.16 (95% CI. -0.45, 0.13) and the standard deviation was 0.40. The t value was -1.23, corresponding to a two-tailed p - value of 0.25 (based on a t distribution of $10 - 1 = 9$ degrees of freedom).

Figure 10: Compositional variation in TEQs of dioxins in ash samples from an open fire pit and an engineered incinerator used for treating clinical waste

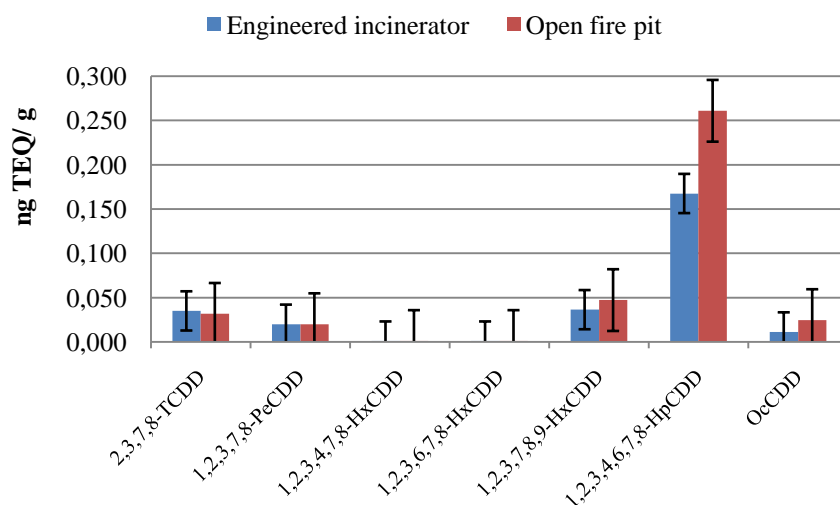
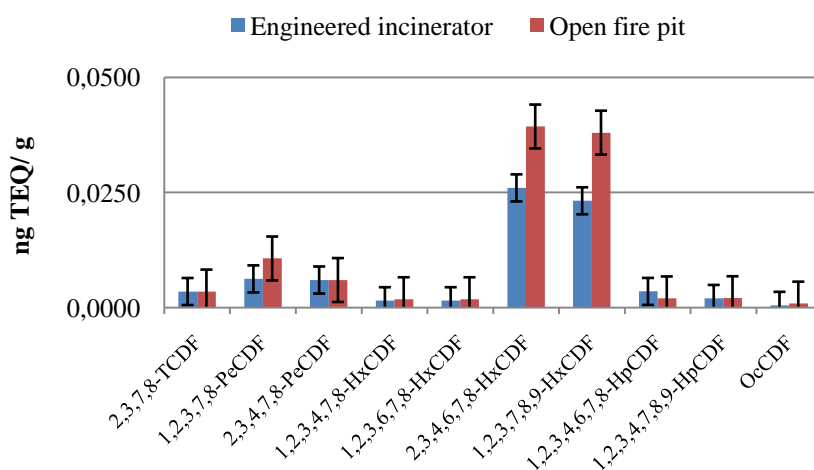


Figure 11: Compositional variation in TEQs of furans in ash samples from an open fire pit and an engineered incinerator used for treating clinical waste



6.5. Child morbidity

The overall response rate for the disease frequency questionnaire was 100%. Summary statistics, risks and risk ratios for the outcomes of interest in the study population during the entire risk period are shown in table six.

Table 6: Summary statistics, risks and risk ratios for respiratory, intestinal and skin infections in the study population during the risk period

Characteristics	Exposed	Unexposed	Total
N	10	10	20
Sex			
Males	6	4	10
Females	4	6	10
Respiratory infection*			
Cases	39	11	50
Non-cases	21	49	70
Risk	0.65	0.18	0.42
<i>Point estimates:</i>			
Risk difference = 0.47 (0.29 - 0.64)			
Risk ratio = 3.54 (2.19 - 5.73)			
Intestinal infection**			
Cases	16	5	21
Non-cases	44	55	99
Risk	0.27	0.08	0.17
<i>Point estimates:</i>			
Risk difference = 0.18 (0.05 - 0.32)			
Risk ratio = 3.20 (1.34 - 7.61)			
Skin infection***			
Cases	19	14	33
Non-cases	41	46	87
Risk	0.32	0.23	0.27
<i>Point estimates:</i>			
Risk difference = 0.08 (-0.08 - 0.24)			
Risk ratio = 1.36 (0.75 - 2.44)			

*chi2 (1) = 26.88, Pr>chi2 = 0.0001; ** chi2 (1) = 6.98, Pr>chi2 = 0.008; *** chi2 (1) = 1.04, Pr>chi2 = 0.306

According to the findings of this study, 39 new episodes of respiratory infection were reported in the exposed group against 11 in the unexposed group during the study period. This means that the 10 exposed children had 39 new episodes of respiratory infection between them compared to 11 for the unexposed children. The risk in the exposed group was 0.65, higher than the risk of 0.42 in both groups while the risk in the unexposed group was 0.18. The risk difference was 0.47 (47%), with a 95% CI of 0.29 - 0.64. The risk ratio (RR) for respiratory infection was 3.54 (95% CI, 2.19-5.73). This means that the exposed children were three and a half times more likely to suffer a respiratory infection than the unexposed children during the risk period. The risk for respiratory infection was statistically significantly (p – value = 0.0001). The values for the lower and upper confidence intervals of the risk ratio also validate respiratory infection as an identifiable risk factor.

Sixteen cases of intestinal symptoms were reported in the exposed group compared with 5 in the unexposed group. On the other hand 44 non-cases were reported in the exposed group compared with 55 in the unexposed group. The risk in the exposed group was 0.27 while the

risk in the unexposed group was 0.08. The total risk between the 2 groups was 0.17, lower than the risk in the exposed group. The risk difference was 0.18 (18%), with a 95% CI of 0.05 – 0.32. The RR for intestinal symptoms was 3.20 (95% CI, 1.34 - 7.60), indicating that exposed children were 3-times more likely to suffer from intestinal infections, when compared with the unexposed children during the risk period. The values of the lower and upper 95% CI also validate the result. The result is also statistically significant (p - value = 0.008).

The reported total number of skin infection was 19 for the exposed and 14 for the unexposed, giving a total of 33 cases in both groups. Non-cases for skin infection were 41 in the exposed group and 46 in the unexposed group, amounting to a total of 87 in both groups. The risk for skin infection in the exposed group was 0.32, higher than the risk of 0.23 in the unexposed group. The total risk in both groups was 0.27, while the risk difference was 0.08 (8%), with a 95% CI of 0.08 – 0.24. The RR was 1.35 (95% CI, 0.75 - 2.44), meaning that the likelihood for skin infection was slightly higher in the exposed compared with the unexposed children. The p – value of 0.306 shows that the result is statistically insignificant, while the values for the lower and upper confidence intervals of the RR indicate that skin infection was less common among the exposed and unexposed children.

6.6. Health impact assessment process

6.6.1. Screening phase

No thorough screening tool was developed for the HIA process since no policy was in place at the time the study was commissioned. The specific risks involved in poor clinical waste management and associated potential public health burden were enough motivations to carry out the process.

6.6.2. Scoping phase

Areas for deep evaluation, as identified by the stakeholders, prior to a clinical waste policy development are summarized in table seven.

Table 7: Evidence base for HIA identified by the stakeholders

	Site of waste disposal	Treatment and disposal methods	Cost of management	Others
1	X	X		X
2	X	X		X
3			X	X
4	X	X		
5				X
6				X
7	X	X	X	X
8	X	X		X
9	X	X		
10		X	X	X
11	X	X	X	
12	X	X	X	
13	X	X	X	
14	X	X	X	X
15	X	X	X	X
Score	11	12	8	10

The two most recurrent areas for deep evaluation are treatment and disposal methods (with a score of 12/15) and site of waste disposal (with a score of 11/15). The cost of management (8/15), including both initial, running and maintenance is also important according to the stakeholders. However, more stakeholders believe that other areas such as the availability of resources (human and otherwise), dialogue between local and international partners and a clear political commitment is just as important. The stakeholders proposed that the government should open consultations with all stakeholders that are directly or indirectly involved in the clinical waste management process. As examples, they identified researchers in state universities for strong evidence base, community groups and service providers to facilitate implementation of the policy and the local government administration for advocacy. Bi/ multilateral partners, including national and international organizations were listed as facilitators and fund providers.

Four of the most important conditions and risk factors (and the total score of each) as listed by the stakeholders are presented in table eight. ‘Others’ constitute those conditions and risk factors which did not identify with any of the four, for example, economic and social setback in the community and risk of explosion or fire at the treatment and disposal site.

Table 8: Important conditions and risk factors associated with poor clinical waste management as identified by the stakeholders

	Physical injuries	Environmental contamination	Breathing ground for vectors	Cross/ auto infection	Others
1	X			X	
2		X	X	X	
3				X	
4	X	X		X	
5				X	X
6	X		X	X	
7	X	X		X	
8	X	X	X	X	
9		X		X	
10		X		X	
11	X	X	X	X	
12	X	X		X	
13	X	X		X	X
14	X	X		X	
15	X	X		X	
Score	10	11	4	15	2

Cross/ auto infection with a score of 15, according to the stakeholders is the most important risk factor when it comes to poor clinical waste management. This could occur through physical injuries which were proposed as a risk factor by 10 of the 15 stakeholders. Environmental contamination of soil, water and air was the next high priority risk factor with a score of 11 among the 15 stakeholders. Poor clinical waste disposal sites as breathing ground for vectors according to the stakeholders is a low priority risk factor.

6.6.3. Risk appraisal phase

Several factors as shown in table nine interact to determine the health effects which can result from poor clinical waste treatment and disposal. All of the determinants are environmental as they fit within the context of poor options for clinical waste treatment and disposal. Other determinants such as the conditions in which people are born and how they live obviously impact their health but does not fit within this context. The inter-relation between the factors emphasizes how challenging it can be to come up with a comprehensive and policy-relevant impact assessment. The type and magnitude of health effects comprehensibly depend on the treatment and disposal method of clinical waste.

Table 9: Determinants of health and potential health outcomes that can be associated with poor clinical waste treatment and disposal

Determinants of health	Source(s)	Potential health impacts/ outcomes	References
Air pollution	Incineration Uncontrolled burning	Cancer Cardiovascular disease Respiratory disease Allergies Annoyance	Allsopp et al (2001) Chen et al (2010) Cohen and Pope 3 rd (1995) Dennekamp and Abramson (2010)
Land and water pollution	Leachate Bottom and fly ash	As above	Allsopp et al (2001) van Grinsven et al (2010) Wang et al (2010)
Odour	Open landfills Open dumps Combustion	Annoyance Anxiety and stress Reduced quality of life	Baker et al (1988) Lipscomb et al (1991) Shusterman et al (1991)
Accident (fire, explosion etc.)	Uncontrolled burning Incineration	Injury Death Risk perception (over or underestimated)	Cutchin et al (2008) Neaman et al (2010) Bishai and Lee (2010)

6.6.4. Evaluation and reporting

Many models for evaluating the process of HIA exist. The one adopted for this HIA is proposed by Quigley and Taylor (2003) and it provides a criterion for product, process, impact and outcome evaluation as shown in table ten. Outcomes usually refer to the health goals underlined in the purpose of the HIA, but in the case of this study, it was the generation of recommendations by stakeholders for a clinical waste management policy for Cameroon.

Table 10: Evaluation criteria for the HIA process

Product (quality of the report)	Process	Impact	Outcome
A manuscript was prepared for publication in a scientific journal.	What the process sought to achieve. Evidence base for potential health effects. How were stakeholders involved in the process? Framing and prioritization and delivering of recommendations.	Stakeholder's perception of the HIA process. The expectations of the stakeholders from the HIA process. Influence of the process on a clinical waste management policy for Cameroon.	Recommendations from stakeholders for a clinical waste management policy for Cameroon.

7. DISCUSSION

7.1. Waste management analysis

One of the specific aims of this study was to investigate the entire pathway of clinical waste management in Cameroon. The main result in this area is typified by the short-comings associated with segregation, collection, transportation, temporal storage and treatment and disposal. Similar situations have been reported in Nigeria (Oke, 2008), where infectious and non-infectious waste are collected in the same dustbin; Botswana (Ketlogetswe et al, 2004), where disposal techniques vary from one centre to another and Iran (Taghipour and Mosaferi, 2009), where segregation is weak and ineffective. These studies suggest that a holistic approach needs to be adopted to successfully manage clinical waste in developing countries. Patil and Shekdar (2001) identified short-comings in the existing clinical waste management system in India. According to the authors, only few establishments contain separate systems for disposal of clinical waste while mixing and co-disposal is common in the others. This was also observed in Cameroon as co-disposal at the rear of hospital premises rendered void ad hoc segregation efforts taking place in the wards and other generation points such as consultation offices of doctors.

A fundamental and very important step in any waste management process is the availability of sufficient and accurate information, including understanding the generation rates and quantities of the materials that needs treatment and disposal (Pruss et al, 1999; Qdais et al, 2007; Diaz et al, 2008). This is because it can be all too easy to ignore a problem about which there are few data (Sagoe-Moses et al, 2001). The existing system in Cameroon is plagued with unreliable and inaccurate data on the quantities and composition of the generated waste, poor planning and lack of adequate budget allocation, including the absence of color-coded storage containers for different categories of waste. None of the hospitals visited during the study kept data on the type and amount of waste they generate. In fact, some directors and employees were surprised at the interest in the quantity of waste they generate. Taghipour and Mosaferi (2009) reported that most cities in Iran dispose domestic and clinical waste together in municipal dumpsites or in poorly designed landfills, or they use on-site waste incinerators that pose operational and maintenance problems. This bears a clear resemblance to what was observed in Cameroon as hospital waste is dumped in municipal waste bins. Despite the difference in current clinical waste management practices in hospitals, the problem areas remain approximately the same at all stages of management (Tsakona, 2007). These processes, according to Girolletti and

Lodola (1993) are important and serve as integral components for any successful waste management process.

The biggest problem in effective clinical waste management in developing countries lies with insufficient resource allocation, lack of training and appropriate skills, risk awareness, public apprehensions and misguided information on exposure, incinerator capacity and the increasing need for a solid and sustainable national health care strategy (HCWS, 2008). These problems arise due to the absence of qualified staff and insufficient training of those available on issues related to efficient clinical waste management and the hazards that might emerge from their inappropriate handling (Tsakona, 2007). These challenges were obvious in Cameroon where janitors most often double as incinerator operators. Nurses were also seen transporting waste to disposal locations. Very little political and financial power is allocated on training and awareness programs as well as selection and construction of suitable treatment and disposal facilities. A national strategy for clinical waste management is a major recommendation of the WHO (WHO, 1999) and such a strategy should be part of a more comprehensive legislation which ensures legal control and orderliness in the clinical waste management process.

The government of Cameroon has taken some steps to improve the current situation of clinical waste management. For example; a national strategy on solid waste management elaborated in 2007 by the Ministry of Environment and the Protection of Nature specifies techniques for prevention, collection and storage, transportation, treatment, and elimination. Another national strategy on the security and management of injection materials developed in 2002, elaborates guidelines for the disposal of such materials, stating that “used syringes and needles should be immediately dropped together in the appropriate receptacles which in this case are the security boxes” and that “In no situation should an injection material be dropped in a public waste bin.” The document also states that “the method to destroy injection materials is by incineration at high temperature and the burial of the combustion residue.” Despite the above mentioned efforts, the situation on the ground remains deplorable thus giving reason to believe that the strategic documents serve more as voluntary guidelines rather than thorough requirements.

7.2. Awareness of hospital workers

Hospital workers, through thorough segregation, can play an important role in minimizing cross-contamination and managing the environmental effects of poor clinical waste treatment and disposal. Their contribution in the waste management process, according to McVeigh (1993), may be less obvious but each effort builds a strong base of sound behavior and thinking necessary for the success of the entire process. The workers at the selected hospitals in Cameroon had a basic knowledge of clinical waste, and a good percentage was neither aware of associated environmental impacts nor policies and guidelines towards efficient clinical waste management. Most of the hospital workers, especially the incinerator operators had received no complaints from the public in relation to existing poor treatment and disposal methods. The workers however showed adequate knowledge and understanding of the health impacts of poor clinical waste management.

A survey report on hospital waste management in Dhaka city by PRISM Bangladesh (2002) revealed that the level of awareness on clinical waste among waste handlers was not good enough to manage the waste systematically. The same report stated that the nurses and staffs were aware of the health impacts of clinical wastes. The Bangladesh study, just like this one, did not apply any predictors of knowledge. But based on anecdotal evidence, one can assume that the hospital workers with longer years of experience are more aware of the associated health impacts of clinical waste. The survey recommended that concerned staffs need to take practical training, rather than the traditional theoretical training, before they are allowed to handle the waste. Some of the identified training needs involved good practices on clinical waste management such as the use for different bins and bags for different waste types and the use of personal protective equipments such as aprons, gloves, gas masks and rubber booths at the appropriate stages of the waste management process.

Worldwide, information on the spread of infection resulting from waste handling is limited (Franka et al, 2009). Salvaged injections (of which poor clinical waste treatment and disposal is a major component), according to some reports, accounts for up to 5% of HIV infections in Africa (Crabb, 2003; WHO, 2003). According to Blenkarn and Odd (2008) and Erdem and Talas (2006), injuries in the hospital environment can occur due to hypodermic needles from poorly closed overfilled containers or from other sharps inaccurately placed in to thin-walled plastic bags. Increasing hospital workers' awareness through repetitive training courses and programs should be given priority in any clinical waste management policy.

Existing laws should be reviewed and their implementation strategy overhauled to identify gaps, so as to facilitate execution and compliance from the public. Summers (1991) emphasize that hospital workers' awareness, as a component of efficient clinical waste management goes beyond the drawing up and introduction of policies and laws. According to Sharma (2010), the awareness of these laws and policies among the general public as well as their involvement in the development and enforcement is essential.

7.3. Standard of clinical waste incinerators

On-site incineration of clinical waste is much favored in developing countries because it is seen as fast and cost-effective. But whether it is a thorough method attracts speculations and major concerns relating to design, operation and maintenance. The three incinerators evaluated in this study all fall short of universally recognized design, operation and maintenance standards for clinical waste incinerators. Rogers and Brent (2006) identified the use of wood-fired sub-standard clinical waste incinerators in Gauteng, South Africa. Ketlogetswe et al (2004) additionally reported the popularity of low technology clinical waste incinerators in Botswana. Most of the low technology incinerators, according to the authors, were in very poor conditions, and as a result the flue gases did not discharge through the chimney, but through cracks and other openings; all of which are consistent with the findings of this study.

The principal purpose of any combustion process is to achieve complete combustion of the organic constituents which might be present in the waste stream. The designs of the three clinical waste incinerators evaluated in this study were to the style of controlled-air incinerators and they mostly burn PVC-rich plastic items. All three lacked vital components such as the very critical secondary combustion chamber, which under high temperature and excess air, completely combust volatile compounds released in the primary chamber (U.S.EPA, 1989). The single chambers in the three incinerators make them unsuitable for clinical waste incineration for two reasons. Firstly, they can result in the generation of huge amounts of bottom ash; which further compounds the PM problem and restrict the combustion process. Secondly, the small sizes of the combustion chambers means that turbulence and mixing is inefficient and combustion air is inadequate, which leads to insufficient combustion temperature and incomplete combustion.

Complete combustion requires sufficient air in the combustion chamber, sufficient temperatures in the combustion bed and combustion gas, sufficient time over which materials

are exposed to a temperature profile, and mixing that assures good contact of the waste/fuel with the combustion air (U.S.EPA, 1989). All these features were lacking in the selected incinerators and as such, could serve as explanation for the columns of black smoke released by the incinerators and/ or account for the high levels of pollutants in the ash samples. During clinical waste incineration, sufficient mixing or turbulence in the combustion chamber is vital as it helps to break up the layer of combustion products formed around a burning particle. The absence of such a process significantly slows down the combustion process as less oxygen makes contact with the combustion particle (OTA, 1988; U.S.EPA, 1989).

The amount and distribution of combustion air between the combustion chambers and the methods used to inject the air are key operating requirements for any clinical waste incinerator. Excess air (above stoichiometric point) in the combustion chamber reduces incineration temperature because the ambient air is heated to combustion temperature. On the other hand, less air also means low temperatures in the combustion chamber as complete combustion has not occurred. It is therefore important to keep the air at stoichiometric point where combustion temperature is maximum. The stoichiometric combustion air is determined by the nature and amount of combustible material to be burnt (U.S.EPA, 1989). Hincrichs (1992) indicated that for complete combustion the incineration operating temperatures should usually be in the range of 850 °C to 1100 °C. While it was not feasible to measure the temperature of the three selected incinerators, one can estimate based on anecdotes that their operating temperatures fall under 500 °C. At such temperatures, and factoring-in the poor state of the incinerators, attaining complete combustion is difficult which makes complete eradication of pathogens doubtful.

7.4. Heavy metals and organics in bottom ash

Clinical waste incinerators may emit a number of pollutants depending on the waste being incinerated and the state of the incineration unit. These pollutants include particulate matter, acid gases, toxic metals and organic compounds of incomplete combustion such as, dioxins and furans, and carbon monoxide, as well as sulfur oxides and nitrogen oxides (Ossama et al, 2005). In our study, heavy metals as well as dioxins, furans, dioxin-like PCBs and PAHs were detected at levels consistent with data reported in (Kuo et al., 1999; Lee et al., 2002; Racho and Jindal, 2004). Note here that the Mozambique results for PAHs, PCBs and PCDD/Fs are applied to the Cameroon context because of the similarities in the clinical waste treatment and

disposal options of both countries. For example, co-disposal and burning in open fire pits is common in both countries.

Researchers at the University of California (Davis) investigated the sources of the two most often found heavy metals- Cadmium and Lead- in clinical waste and concluded that plastics in the waste mostly contributed to the presence of the two metals (Lee and Huffman, 1993). Their report stated that Cadmium is used as a component in common dyes and as thermo- and photo stabilizers used in plastics while Lead is common in materials such as paper, inks and electrical cable insulation, and it is also used to make dyes and stabilizers for plastics. It is ironic to note that the pigments made from Pb and Cd are used to color plastic bags, which means that part of Pb and Cd emission could be from incinerating the 'red bag' used for collecting and storing infectious waste (Lee and Huffman, 1993). In our study, Cd was reported at below the limit of detection in bottom ash samples from the three selected incinerators. The absence of 'red bags' at the three selected hospitals could be the reason for this finding. The presence of Lead could be due to the large amount of ink-tainted cardboards and utility gloves in the clinical waste stream.

Kuo et al (1993) reported that high levels of Ni, Cr and Fe in ash samples from clinical waste incinerators in Taiwan could be as a result of the fact that the hospitals do not grind or melt down needles or syringes at high concentrations. Their results were consistent with two incinerators (A and B) in this study, and so one could suggest similar explanations as facilities for grinding and/ or melting needles were absent at the hospitals running the incineration units. On the other hand, no concrete reason could be used to explain the low levels of Ni and Cr in the ash samples from incinerator C as facilities for grinding and/ or melting were not present at the hospital running the incineration unit.

Several scientific publications have linked the high chlorine content in clinical waste streams to the high levels of organic emissions -both as gaseous and solid by-products- from clinical waste incinerators (U.S.EPA, 1990, 1994; Wagner and Green, 1993). An explanation comes from the fact that each molecule of dioxin, furan, dioxin-like PCBs and PAHs contain at least two atoms of chlorine; which makes the amount of chlorine-rich items in the waste stream a serious contributing factor to the amount of chlorinated organic compounds released by an incinerator. Shane et al (1990) identified the operating conditions of the combustion medium to be largely responsible for the concentration of organic compounds in ashes. Other conditions

according to Huang and Bueckens (1996) include the presence of fly ash, metal ions and a temperature range of 250 – 450 °C.

Waste composition, temperature and excess air during incineration determine the quantity of PAHs emitted by a given facility through pyrolysis and pyrosynthesis (Singh and Prakash, 2007). The compositional variation in the levels of the congeners in both ash samples was conspicuous, and high in some compounds, especially PAHs. The levels of some congeners such as naphthalene, acenaphthalene and anthracene were between 2 – 3 times higher in ash samples from OFP compared to that from EI. Considering that the production and emission of PAHs is directly affected by type of combustion (Shane et al, 1990), especially combustion temperature (Mastral et al, 1999), the high levels in the OFP was expected because burning was uncontrolled and carried out at a low temperature, presumably < 400 °C, suitable for PAH production (Valavanidis et al, 2008). The variation could also be linked to the physical and chemical characteristics of the compounds, which vary with molecular weight (MW), with resistance to oxidation, reduction and vaporization increasing with increases in MW, while aqueous solubility decreases (Maliszewska-Kordybach, 1999). The Σ PAHs in the EI, at 3784.1 ng/g, was conspicuously high when compared with 162 ng/g in ash samples from a mechanical grate clinical waste incinerator reported by Lee et al (2002). The reason could be because of the fact that the EI was often over loaded and poorly maintained.

Hutzinger et al (1985) noted that data and theories in the literature support the theory of de novo formation of dioxin-like PCBs, PCDDs and PCDFs (i.e., thermochemical synthesis from chemically unrelated precursors including naturally occurring substances) at different temperatures. According to the authors, there is general agreement that higher levels of PCDDs and PCDFs are likely produced by more direct thermal conversion processes involving polychlorophenols, PCBs and polychlorobenzenes. Using a fly ash model system, Stieglitz et al (1989) showed that PCBs (as a group) were formed from particulate organic carbon and they expected the same behavior for the formation of dioxin-like PCBs.

Despite the compositional variation in congeners, the levels of dioxins in both ash samples in this study increased with homologue chlorination profile. Starting with low levels at the tetra- homologue, the concentration steadily increases with chlorination attaining the highest concentration at the octa- homologue. Such a homologue profile, according to Vehlow et al (2006) is characteristic with dioxins in solid residues. Furans show an opposite homologue profile in solid residues with the lowest chlorinated homologues typically having the highest

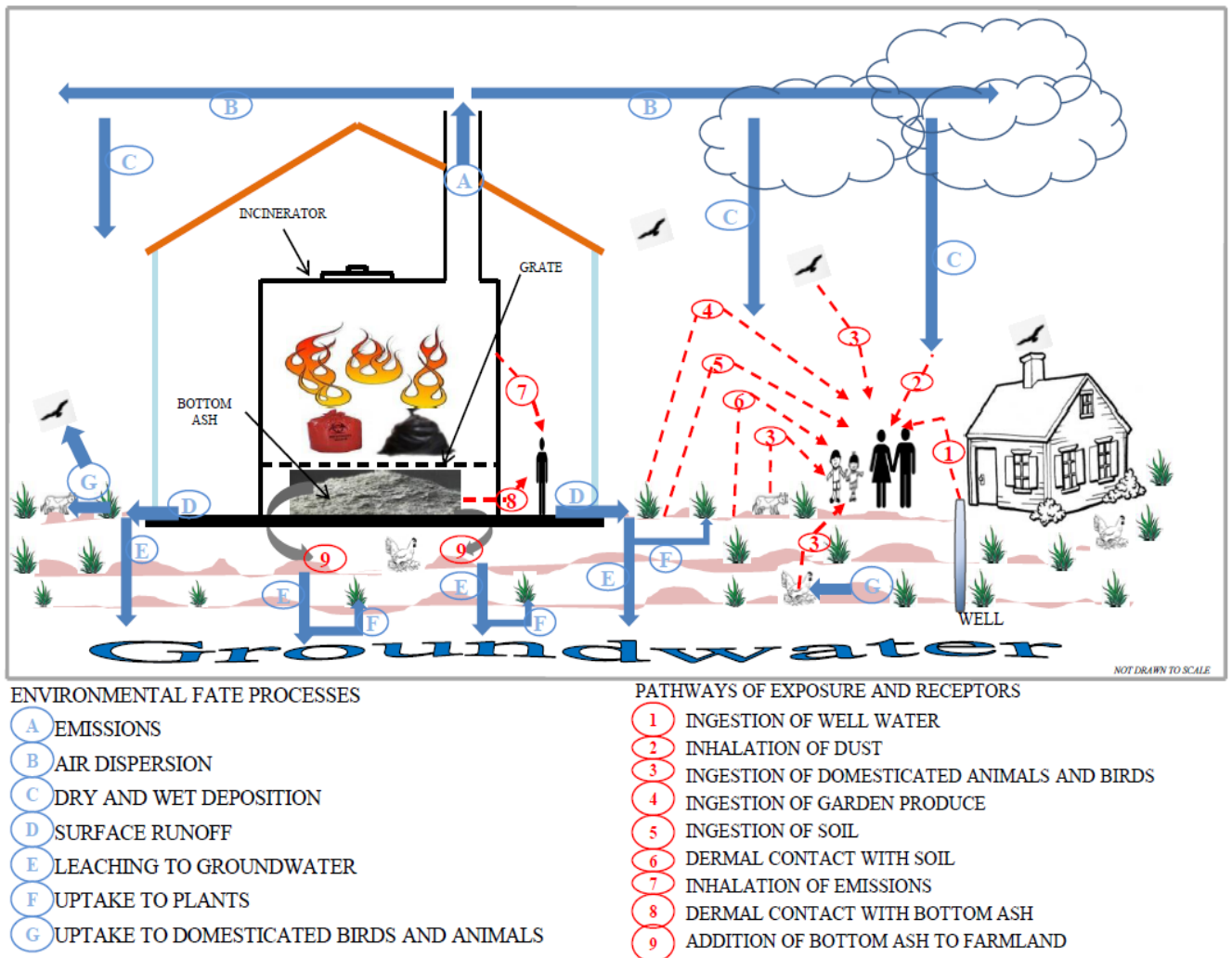
concentrations (Klicius and Finkelstein, 1988). Furans in this study did not reveal such a profile as the octa- homologue had the highest concentration in the ash samples. No scientific explanation could be associated with the homologue profile. The levels of dioxin-like PCBs and PCDD/Fs in the EI were high when compared to reported levels (Gidakos et al, 2009; Grochowalski, 1998) from standard small-sized incinerators. Poor adjustment and operation of the automated fan system in the EI could be a serious contributing factor as well as the absence of a credible waste management culture in the hospitals that manages the facility. Uncontrolled burning at low temperatures could be responsible for the high levels of the compounds in the open fire pit.

7.4.1. Site conceptual model and potential exposure pathways

The presence of residential areas, with gardens and domestic animals and birds within the vicinity of say a sub-standard clinical waste incinerator poses risks to human health. This eventually necessitates the development of efficient risk assessment tools such as a site conceptual model which can adequately portray the primary contamination source and the potential exposure pathways by which different types of human populations might come into contact with contaminated media. Carlon et al (2001), report that site characterization is the basis for risk assessment. It is believed that the model proposed in figure 12 will facilitate data collection activities and the estimation of health risks.

The model demonstrates the main risk source, which in this case happens to be a sub-standard clinical waste incinerator. It is important to note that a typical poor clinical waste treatment and disposal site in most third world countries is characterized not only by the presence of a sub-standard incinerator, but with other primitive options such as open landfills, open fires and uncontrolled dumping. The environmental fate processes of emissions and by-products from the incineration process are demonstrated by the thick blue arrows labeled with the letters A to G. Pathways of exposure are represented by the thin red broken arrows labeled from 1 to 8.

Figure 12: Site conceptual model for a sub-standard clinical waste incineration site.



The numbers 1 to 6 represent indirect exposure at the community level, especially those within the vicinity of the site. Some of the exposure routes include the probable ingestion of well water, inhalation of contaminated dust, ingestion of domesticated animals and birds and the ingestion of garden produce represented by the numbers 1-4 respectively. Batterman (2004) noted that these pathways are important for persistent pollutants because they can bioaccumulate in to food. The numbers 7 and 8 represent direct occupational exposure by, notably, incinerator workers. It is important to bear in mind that incinerator operators can be susceptible to both direct (when at work) and indirect (when in the community after work) exposures. Exposure can be through the inhalation of gaseous emissions and/or through dermal contact with bottom ash. Number 9 can be classified as both an environmental fate process; for the bottom ash, and as a pathway of exposure of both incinerator workers and gardeners. The incinerator workers can make dermal contact with the ash when cleaning the incinerator. Gardeners also make dermal

contact with the ash when mixing it with soil on their farmland. Exposures can extend to the local community level through the consumption of garden produce and stray domesticated birds and animals feeding in the garden and around the site. Batterman (2004) identified some challenges in predicting and validating indirect exposure pathways for sub-standard incinerators. According to the author, these include the following:

- The limited data available on both communities surrounding incinerators (demography, occupations, health status, etc.) as well as environmental conditions (types and concentrations of air contaminants present, etc.).
- The wide variety of environmental settings.
- The poor quality of the emission data.
- The lack of validation of the exposure assessments.

7.4.2. Metal toxicity

According to Lee and Huffman (1993), toxic metals in clinical waste are not destroyed during incineration; they instead change their chemical and physical states and are released via gaseous and solid by-products. Metals such as Ca, Mg, Zn, Pb, Ni, Mn, Fe, Cu and Cr were identified in ash samples in our study. The solubility and mobility potentials of the aforementioned metals are vital for activity in environmental media. Solubility is dependent on factors such as the concentration of the metal, chemical species, pH, redox potential and ionic strength of the soil solution. Mobility on the other hand is influenced by organic carbon content, Fe, Mn and Al oxide content, pH and redox potential. Nonetheless, Cr and Ni are known carcinogens (Martel, 1981), Pb an uncertain carcinogen, and Fe and Cu are uncertain co-carcinogens (Martel, 1981). The mechanisms of action of carcinogenic metals according to Beyersmann (2002) are still far from being elucidated completely. Nickel, Cr and other carcinogenic metals such as Cd and Co are known to enhance mutagenicity and carcinogenicity by directly acting on genotoxic agents (Beyersmann, 2002).

Lead serves no useful purpose in the human body and its toxicity needs little introduction. Its presence in the body can lead to toxic effects, regardless of exposure pathway (ATSDR, 2005). Lead toxicity can affect every organ system; the nervous system being the most sensitive target. On a molecular level, proposed mechanisms for toxicity involve fundamental biochemical processes. These include Pb's ability to inhibit or mimic the actions of

Ca (which can affect Ca-dependent or related processes) and to interact with proteins (including those with sulfhydryl, amine, phosphate and carboxyl groups) (ATSDR, 2005).

The importance of Fe and Cu is well known, but information on their toxicity is insufficient except for the genetic overload diseases, Wilson's disease and hemochromatosis (Brewer, 2010). As transition metals, their redox properties have been used during evolution in the development of oxidative energy generation. On the other hand, they both contribute to the production of excess damaging oxidant radicals which build-up in humans with age, and have subsequently been associated with diseases of aging such as Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis and diabetes mellitus (Brewer, 2010). Brewer (2010) reported findings of a study in which people in the highest fifth of copper intake, and who also eat a relatively high fat diet, lose cognition at over three times the normal rate.

7.4.3. Toxicity equivalence quantities (TEQs)

Potential public health risks from environmental exposures to chlorinated dioxins and related compounds continue to be the subject of much research, regulation, and debate (Charnley and Doull, 2005). The U.S. Environmental Protection Agency has estimated that > 95% exposures to dioxins are through low-level contamination of the food supply (U.S.EPA, 2000). Dioxins and other dioxin-like compounds exist in environmental and biological samples as complex mixtures of various congeners; a characteristic that presented challenges to reliably estimate their toxicity (Van den Berg et al, 1998). The WHO established the TEFs approach which estimates TEQs for the congeners of dioxins, furans, PAHs and dioxin-like PCBs relative to the most potent congener in each class of compounds. Congener concentrations can be converted into 2,3,7,8-TCDD TEQ (the case of dioxins) concentrations; calculated by multiplying the concentration of each congener by its 2,3,7,8-TCDD TEF for humans and mammals (Wang et al, 2008). The TEQ approach is widely applied in risk assessment studies (Van den Berg et al, 1998). It is important to emphasize that there is no mechanistic comparability of TEQs calculated for PCBs/PCDD/Fs and PAHs. This is because TEQ activities are based on two separate compounds; benzo-a-pyrene for PAHs and 2,3,7,8-TCDD for co-planar PCBs and PCDD/Fs.

The TEQ of total 15PAHs in the EI and OFP was 729.24 ng TEQ/g and 2801.25 ng TEQ/g respectively. For dioxin-like PCBs it was 0.016 ng TEQ/g in the EI and 0.011 ng TEQ/g

in the OFP. For PCDDs, the TEQ was 0.272 ng TEQ/g in the EI and 0.386 ng TEQ/g in the OFP. The TEQs for PCDFs was 0.074 ng TEQ/g in the EI and 0.106 ng TEQ/g in the OFP. PAHs are, based on the results (very high TEQ values), the compounds of concern in terms of toxicity of bottom ash (from poor clinical waste incineration) to humans, mammals and birds. D[a,h]A contributed the most TEQ of approximately 86% and 81% in EI and OFP respectively. PCB126 contributed the most TEQ of approximately 95% and 92% in EI and OFP respectively. 1,2,3,4,6,7,8-HpCDD contributed the most TEQ of approximately 61% and 67% in EI and OFP respectively. 2,3,4,6,7,8-HxCDF contributed the most TEQ of 35% and 37% in EI and OFP respectively. The ash from OFP and EI is therefore most harmful to humans and mammals; with high level PAH contamination a serious threat.

Reliable data and evidence on the toxicity of dioxins in humans exist on high level occupational exposures and industrial accidents, such as the Seveso industrial accident (Hay, 1976; Liem et al, 2000). Such evidence is, however, limited for chronic low-level exposures (Batterman, 2004; Grassman et al, 1998). Acute exposure to dioxins is associated with skin lesions and altered liver function, while long-term or chronic exposure is associated with major systemic impairments such as the immune system, the developing nervous system, the endocrine system and reproductive system (Batterman, 2004; Charnley and Doull, 2005; Grassman et al, 1998). Current chronic low-level exposure to dioxins from sub-standard incinerators in developing countries is unknown, but is expected to be significant considering that such exposures represent incremental exposures adding to baseline exposures (Batterman, 2004). Consequently, the use of sub-standard incinerator ash to enrich agric fields (gardens) should be discouraged. The results from this study provide critical information with regard to hazard identification and selection of appropriate clinical waste incineration ash management plans.

7.5. Morbidity and poor clinical waste disposal

After assessing the situation in 22 developing countries, the WHO revealed that the proportion of healthcare facilities that do not use appropriate waste disposal methods ranges from 18% to 64% (WHO, 2005). Such a situation leaves residents (particularly children) around hospitals in developing countries in great danger of contamination. Raised incidence of low birth weight births has been related to residence near landfill sites, as has the occurrence of various congenital malformations (Rushton, 2003). Other health problems associated with proximity to a waste disposal site comprehensively reviewed by Vrijheid (2000) are composed

of specific and non-specific symptoms. The specific symptoms included irritation of the skin, eyes and nose, gastrointestinal and respiratory problems. The non-specific symptoms, on the other hand, included headaches, fatigue, allergies and psychological problems. The author identified that, due to issues related to population dynamics and susceptibility patterns, direct and more precise exposure quantification was a challenge. This could be the reason why there are so few studies linking poor treatment and disposal units for clinical waste to purported health outcomes.

Living in proximity to a poor clinical waste disposal site, according to our findings, presents a risk ratio (RR) of 3.54 (95% CI, 2.19-5.73) for respiratory infection in children. In other words, children living close to a poor clinical waste disposal site likely suffer 3½ times more from respiratory associated symptoms than unexposed children living far away from such dump sites. The risk for respiratory infection was statistically significant (p -value = 0.0001) for the exposed compared with the unexposed. Increased episodes of respiratory infection have been reported in neighborhoods close to municipal waste dump sites but not clinical waste dump sites. For example, Heller and Catapreta (2003) reported a less evidenced relationship between respiratory diseases in a nearby community bordering a solid waste disposal site in Belo Horizonte, Brazil. The authors observed that the site contained treatment and disposal facilities with design and operational problems and deposits of waste which can end up providing a likely location for proliferation of diverse vectors and favoring uncontrolled emission which may affect health for both the people at work and those living nearby. This observation corresponds with the existing situation at the clinical waste treatment and disposal location in the Northwest region of Cameroon. Other studies have associated exposure to a waste dump site and several hazardous waste disposal sites with larger probability of respiratory symptoms in children, as well as irregular heartbeat, history of heart problems, cases of anemia and other blood disorders in people neighboring such sites when compared with a control (Ozonoff et al, 1987; Girón et al, 2009).

Intestinal symptoms had a RR of 3.20 (95% CI, 1.34 - 7.60) which indicates a 3-times likelihood for intestinal symptoms in exposed compared to unexposed children. Its associated p -value of 0.008 indicates that it is statistically significant. Intestinal infections are globally known to be endemic and constitute the greatest single worldwide cause of illness and disease (Mehraj et al, 2010). Gazon (2003) and Steketeer (2003) mentioned that intestinal infections occur to people of all ages; with children having the worst morbidity and mortality. A study of primary

school children in Cameroon aged 9-16 revealed that infection rates with intestinal nematodes were as high as 98% in some rural areas (Akufongwe et al, 1995). In a more recent study, Fogwe and Ndifor (2010) investigated intestinal nematodes in urban dwellers in the city of Douala, Cameroon and found that children (aged 5 to 9 years) were most affected (88.9%) as opposed to adults. Explanations to the aforementioned findings can be borrowed from Curtale et al (1999), where they state that demographic (age of the children), behavioral (washing of hands) and environmental (settlement) factors are major determinants. Other explanations according to the authors could be linked to socioeconomic status and cultural beliefs. In a recent study, Mumtaz et al (2009) listed other risk factors such as poor hygienic conditions, impure drinking water and low literacy rate of parents, large family size and poor health status of the child.

Skin infection had a RR of 1.35 (95% CI, 0.75 - 2.44); meaning that the likelihood was almost the same in the exposed as with the unexposed children. The *p*-value of 0.306 indicated that it was statistically insignificant. In developing countries, skin infections account for a high proportion of ambulatory visits by children. For example, in Ghana Belcher et al (1977) reported that they fall in the fifth most frequent diagnostic category. As stated by Figueroa et al (1997) and Bailie et al (2005), skin infections (especially bacterial skin infections) are a common and important cause of morbidity in children, especially in communities with meager resources. During the search for play items such as syringes and intravenous sets, the children in our study expose parts of their body to insect bites and different types of germs. For example, they are sometimes without shoes and often wear shorts and sleeveless t-shirts. Such attire increases the possibility for dermal exposure and possible contact with germs and substances (in salvaged items) that can cause various infections and allergic reactions. The likelihood that the children do not have regular and complete bath after playing on the dumps including access to other hygienic conditions such as clean toilets can also be responsible for the proportion of skin infections.

Treatment and disposal of clinical waste in Cameroon as previously mentioned involve the use of rudimentary incinerators, open dumps, and poorly constructed landfills for solid wastes while liquid waste is flushed to suck-away pits via toilets and sinks. Disease vectors such as flies, mosquitoes and rodents, which potentially transport germs in to households in close proximity, are attracted to such sites. Clouds of visibly black smoke and fly ash from the incinerators, through mass air movements deposit pollutants around the households and on to

the waste dumps. Foul smell from potential mercaptans (Vadic et al, 2000) is common around the area. Children living within the vicinity of the sites, as it was observed, access the dump sites to salvage (particularly) needles and intravenous sets to be used as play items. Despite the small sample size and short period of data collection, the results paint a picture of the exposures and health risks for children living in such sites. It is evident from the findings that poor clinical waste treatment and disposal methods can enhance morbidity in the community even though there is insufficient evidence of them causing morbidity. The findings further indicate that a simple intervention technique such as relocation of the treatment, disposal and dump site can significantly reduce morbidity, especially in children, in communities neighboring such sites.

7.6. Prospective policy development through HIA

Health impact assessment has been widely accepted as a key tool to link science and decision making, offering unique opportunities for the protection and promotion of human health (Fehr et al, 2004). Part of the initial aims of this study was to conduct an HIA of existing clinical waste management policy for Cameroon. As such a policy did not exist at the time of the study, the process turned to focus on prerequisites and needs for such a policy such as evidence-based recommendations for decision makers. The process also aimed at facilitating the identification of negative health impacts which can be associated with poor clinical waste management; which will later be given due consideration in the decision making process. Additionally, the HIA process would emphasize the necessity for a working partnership between decision makers and stakeholders throughout the decision making process.

Community involvement as a key and active stakeholder is one of the key tools underlying HIA, even though full community representation can be difficult to achieve especially from the hard-to-reach groups (Petticrew et al, 2004). Due to insufficient time and limited resources, we could not consult with all the communities which are directly affected by poor clinical waste management in Cameroon, and who by default would be those to benefit most from the development and implementation of a robust policy. We selected 15 key stakeholders with sound experience, knowledge and information relevant to the subject of the HIA.

Through the HIA process, stakeholders proposed conditions and risk factors in the current clinical waste management process which can lead to negative health impacts, and they also identified strong evidence areas in support of the HIA process. Treatment and disposal

methods such as dumping and sub-standard incineration, site (location) of disposal unit, cost of managing clinical waste and others such as misguided apprehensions in the community can be potential sources for evidence to support HIA process. Joffe and Mindell (2002) state that, in literature, nine ways can be distinguished in which evidence on health and its determinants can be related to policy; the most complete of which is an analysis of health effects in the context of a comparison of options. Such an approach will be vital for decision makers as they are faced with the responsibility of selecting the most cost-effective and environmentally friendly option for effective clinical waste treatment and disposal, considering that there is no single option of waste treatment or disposal that completely eliminates all risks to the public or the environment (Diaz et al, 2005).

Prediction of the health impacts of any intervention depends on a synthesis of all available evidence to produce an estimate of the likely effect and the application of this estimate to the affected population (Parry and Stevens, 2001). The authors identified McIntyre and Petticrew (2000) for noting that “the identification and incorporation of relevant evidence, its appraisal for methodological soundness and relevance, and its incorporation with qualitative evidence is likely to be difficult, but crucial to the validity of health impact assessments.” A review of relevant evidence from the published literature was undertaken for the risk appraisal phase. The purpose of this was to identify published evidence of the effects of similar methods on the health of populations. In addition, up to date evidence of the effects of key determinants known to be affected by the methods, such as air, soil and ground water quality and their impacts on health was also reviewed. Since community representation was not fully achieved throughout the HIA process, and time and resources were insufficient, it was difficult to come up with estimates of likely health impacts especially on the community neighboring the disposal units.

Air, land and water pollution, including unintended fire accidents, can determine health impacts which can be associated with poor clinical waste treatment and disposal. The influence of the factors on each other emphasizes how challenging it can be to come up with a comprehensive and policy-relevant impact assessment (Kjellstrom et al, 2003). The type and magnitude of health effects comprehensibly depend on the treatment and disposal method. For example, pollutants from regular sub-standard incineration can affect air and soil quality around such sites. Therefore any criteria developed to facilitate decision making and selection of a treatment and disposal method would need to suit specific considerations such as the amount of

clinical waste generated by a facility, segregation measures put in place, the material and human resource potential of that facility with respect to operation and maintenance. Other considerations would be the site of the treatment or disposal unit with respect to community proximity. Also information on the geology of the area with respect to the level of ground water is important especially when land filling is under consideration.

8. CONCLUSION

Despite the fact that poor treatment and disposal of clinical waste poses potential hazards to environmental and public health, it has attracted little attention within the spectrum of environmental risks and public health research. Our study identified shortcomings associated with the current clinical waste management process in the Northwest region of Cameroon. The shortcomings stem primarily from inadequacy in health care workers and insufficient training of the available ones on the potential hazards of clinical waste and its poor management. Other reasons could be inertia from the government and hospital administrators. The waste management system needs a complete overhaul, with improvements during collection, segregation, transportation, temporal storage and treatment and disposal.

Inappropriate measures were applied for clinical waste treatment and disposal at the region of study; a situation that is familiar with the other primary healthcare clinics and referral hospitals in Cameroon. Open and safe landfills, surface dumps and sub-standard incineration were common. In view of these problems, affordable and practicable technology solutions are required in the region in particular and Cameroon as a whole. Relatively low cost small-scale incinerators can be used at rural primary healthcare centers while an integrated clinical waste management system; with a centralized larger-scale double chambered air-control incinerator can be used at the bigger urban hospitals. With a robust segregation culture, such a system guarantees cost-effectiveness and the incinerator (through constant maintenance) will provide compliance with emission and operational requirements.

Bottom ash from sub-standard clinical waste incineration harbor large amounts of PAHs, including PCDD/Fs, dioxin-like PCBs and heavy metals as has been revealed in this study. Human exposure to these compounds and metals occur primarily through ingestion and/ or skin contacts. The act of deliberately applying the ash on farm lands is driven by lack of awareness. It should therefore be discouraged as the pollutants can contaminate soil and ground water, leading to incremental build-up in the food chain.

Living in close proximity to a poor clinical treatment and waste disposal site can be a major underlying factor in poor child health, especially as it enhances respiratory, intestinal and skin infections. The high relative risk for respiratory infection can be associated with the emissions resulting from the uncontrolled and frequent burning of clinical waste in the open pits and sub-standard incinerators. The relative risk for intestinal infections was high too, and possible explanation is linked to demographic, behavioral, cultural, socioeconomic and

environmental factors. Skin infection was relatively low, compared to the others, due to the difficulty the parents (who are not professionals) can face in identifying them. The children can, for example, hide skin infections and only report when the discomfort becomes unbearable. The commitment shown by the parents of the children towards the success of this study confirms the urgent need for better clinical waste management and efficient and secured treatment and disposal options. Simple health promotion and/ or intervention program such as relocation of the treatment and dump site can curb morbidity and subsequent primary health care visits. It is important that such an effort is not seen as increases in expenditures but as investments in the protection of public and environmental health. Additionally, a reduction in morbidity will, most certainly, allow the parents to divert resources towards areas such as education and provision of other social needs of the children.

The small sample size of 20 children was a major limitation of this study. Hospitals (and their on-site treatment and disposal units) are located within communities where the sizes are often small (about 10 to 20 houses), and their demography is constantly changing. This makes it difficult to recruit a substantial sample size. Identifying several neighbourhoods within the vicinity of similar treatment and disposal units for clinical waste could be an approach to overcome this difficulty in future related studies. The approach of not clinically investigating the infections, especially intestinal infection, and relying on the subjective judgement of the parents was another limitation. The possibility for cross contamination, especially with respiratory and skin infections, is another limitation of this study. Since the children were always together, it was difficult to identify those who got infected as a result of direct exposure and those who were infected as a result of indirect exposure to the treatment and disposal unit. Some of the homes, compared to others, were closer to the disposal site and this can have a bearing on exposure in the homes. To more definitively investigate this preliminary association in the future, a larger sample size and an enhanced study design is a major recommendation.

The overall success of the HIA process shows the necessity to improve clinical waste management in Cameroon through the development of a robust policy that seeks to promote environmental sustainability, and strive to eliminate negative public health impacts. The stakeholders welcomed the HIA initiative as it sought their valued contributions and can ensure transparency in the policy making process. There was skepticism towards its application in all decision-making processes in Cameroon. This is because, unlike EIA, there is no formal acknowledgement of HIA in Cameroon. Policies and programs are drawn-up with little or no

public participation and insufficient consideration is given to potential undesired and/ or unintended health outcomes. The existing structures of EIA in Cameroon can tremendously facilitate the integration of HIA. For example, article 17 of Law N° 96/12 of 5th August 1996 that prescribes EIA for all projects in Cameroon can be re-drafted to include the necessity for HIA in all policies and projects. Additionally, a permanent secretariat can be created in the Ministry of Public Health (just like the permanent secretariat in the Ministry for Environment and Protection Nature responsible for ensuring effective EIA nationwide) and charged with the responsibility of ensuring the nationwide expansion of HIA through capacity building and coordination of different HIA initiatives.

The HIA process had some limitations at its onset. A thorough screening tool was not used or developed during the screening phase due to the absence of a clinical waste policy or guideline in Cameroon at the time this study was carried out. However, a set of recommendations for policy development is proposed due to the environmental and public health burden of poor clinical waste management. Another limitation was the lack of a comprehensive risk appraisal of risk conditions, factors and health outcomes. It was not possible to assess the number of people exposed to noise and gaseous pollution from the incinerator and contamination from using incinerator ash on gardens and farmlands due to the predominantly desktop nature of the process. Scoping phase was conducted via emailing questionnaires to the stakeholders. This eliminated the one-on-one consultation process and limits the validation of data quality and reliability.

Traditionally, recommendations from stakeholders during an HIA are oriented towards minimizing negative health impacts and maximizing health gains from a policy, program or project. In our study, stakeholders recognized that improving the current clinical waste management process will minimize risk factors such as cross/ auto-contamination through physical injuries, and environmental pollution, which will ultimately curb associated negative impacts on health. Their recommendations were therefore oriented at improving the current situation. An exhaustive list from the stakeholders was condensed to seven key recommendations based on international guidelines. The recommendations include:

- The presence of a strong political and economic will from the central government. This can guarantee investments in both human and material resources which can lead to effective solutions in both the immediate and long term.

- Financial and technical support from international organizations such as the WHO and UNEP. These organizations, including others such as the World Bank, contain the resources and expertise to the development, implementation and monitoring of such a policy.
- Development of a robust policy on clinical waste management. This is linked to the commitment from the central government and its negotiations with foreign agencies discussed in points one and two above.
- Participation of stakeholders in the policy making process is necessary not only to ensure transparency, but to also guarantee that the deliverables of the policy making process will be adherent to stated aims and needs.
- Encourage research in the area through the creation of data support systems in areas such as types and amount of clinical waste generated and environmental monitoring of soils and emission factors for sub-standard incinerators. Statistics on different exposure scenarios, of say healthcare workers, should be created and constantly updated as it will help track the progress and success of any control effort.
- Develop and encourage continuous training and awareness campaigns for hospital workers and members of the public. Training in the area of waste segregation and safe transportation should target hospital workers, while local sensitization campaigns such as town hall meetings on the dangers of clinical waste could help curb hypothetical fears from the public.
- Encourage professionalization and commercialization of the sector taking in to consideration the 3Rs (reduce, reuse and recycle) of waste management.

8.1. Further research perspectives

1. *Assessment of surveillance and monitoring systems for occupational exposure to clinical waste under a variety of conditions in developing countries.*
Poor sharp disposal remain an important threat to nurses, laboratory technicians and waste pickers. Most developing countries lack a well functioning surveillance and monitoring system. An assessment and strengthening of such a system will greatly reduce risks.
2. *Empirical risk assessment tools for chronic low level exposures from sub-standard incinerators in developing countries.*
Sub-standard clinical waste incinerators contribute significant proportions of persistent organic pollutants to the environment. However, validated risk assessment tools for chronic low level exposure by vulnerable populations, especially those within the vicinity of the unit are lacking.
3. *Training and intervention studies on awareness and risk management.*
Hospital workers lacked adequate training and awareness on both clinical waste management and health risks of clinical waste respectively. Such training and intervention studies will, for example, come-up with specific training and intervention programs that fit well with the needs of the hospital workers.
4. *Best management practices for standard small scale clinical waste incinerators.*
Standard small scale incinerators, such as the engineered incinerator in Mozambique, are expected to comply with emission standards. However, operation of these facilities far beyond their capacities (as the case in Mozambique) seriously restricts their ability to function properly. It is thus imperative to develop guidelines on how to manage these incinerators in order to keep their emissions in compliance with stipulated standards.

9. REFERENCES

- Abor, P.S., Boucher, A. (2008). Medical waste management practices in a Southern African hospital. *International Journal of Health Care Quality Assurance*, 21(49); 356-364.
- Agency for Toxic Substances and Disease Registry (ATSDR, 1994). Toxicological Profile for Chlorodibenzofurans (CDFs). US Agency for Toxic Substances and Disease Registry, Department of Health and Human Services, Public Health Service, Atlanta, Georgia.
- Agency for Toxic Substances and Disease Registry (ATSDR, 1998). Toxicological Profile For Chlorinated Dibenzo-*p*-Dioxins (CDDs). US Agency for Toxic Substances and Disease Registry, Department of Health and Human Services, Public Health Service, Atlanta, Georgia.
- Agency for Toxic Substances and Disease Registry (ATSDR, 2002). Toxicological Profile for Polychlorinated Biphenyls (PCBs). US Agency for Toxic Substances and Disease Registry, Department of Health and Human Services, Public Health Service, Atlanta, Georgia.
- Agency for Toxic Substances and Disease Registry (ATSDR, 2005). Toxicological profile for Lead. US Agency for Toxic Substances and Disease Registry, Department of Health and Human Services, Public Health Service, Atlanta, Georgia.
- Akter, N. (2002). Medical waste management: A review. Pathumthani, Thailand. Asian Institute of Technology. Available from: <http://www.engconsult.com/BEN/papers/Paperanasima.PDF>
- Akufongwe, P.F., Onwuliri, C.O., Titangi, V.P., Okwuosa, V.N. (1995). Prevalence of Schistosomiasis and other intestinal helminth infections among senior primary school children in Makenene sub-division, Cameroon. *J. Helminthol*, 65; 103-105.
- Al-Mutair, N., Terro, M., Al-Khaleefi, A.L. (2004) Effect of recycling hospital ash on the compression properties of concrete: statistical assessment and predicting model. *Building Environment*, 39; 557-566.
- Alagoz, B.A.Z., Kocasoy, G. (2007). Treatment and disposal alternatives for health-care waste in developing countries – a case study in Istanbul, Turkey. *Waste Manage Res*, 25; 83-89.
- Allsopp, M., Costner, P., Johnston, P. (2001). Incineration and human health: state of knowledge of the impacts of waste incinerators on human health. Greenpeace Research Laboratories, University of Exeter, UK.
- Alvim Ferraz, M.C.M., Alfonso, S.A.V. (2003a). Dioxin emission factors for the incineration of different medical waste types. *Arch. Environ. Contam. Toxicol.*, 44; 460-466.
- Alvim Ferraz, M.C.M., Alfonso, S.A.V. (2003b). Incineration of different types of medical wastes: emission factors for particulate matter and heavy metals. *Environ. Sci. Technol.*, 37; 3152-3157.
- Alvim Ferraz, M.C.M., Barcelos Cardoso, J.I., Ribeiro Pontes, S.L. (2000). Concentration of atmospheric pollutants in the gaseous emissions of medical waste incinerators. *J. Air and Waste Manage. Assoc.* 50:131-136.
- Azage, M. and Kumie, A. (2010). Healthcare waste generation and its management system: the case of health centers in West Gojjam Zone, Amhara Region, Ethiopia. *Ethiop. J. Health Dev*, 24(2); 119-126.
- Barkely, W.E., Wedum, A.G., McKinney, R.W. (1983). The hazard of infectious agents in microbiological laboratories. (In. Block SS, Ed., Disinfection, Sterilization and Preservation) Third edition, Lea and Febiger, Philadelphia.
- Batterman, S. (2004). Findings on an assessment of small-scale incinerators for health-care waste. Water, Sanitation and Health Protection of the Human Environment, World Health Organization. Geneva, Switzerland.
- Bailie, S.R., Stevens, R.M., McDonald, E., Halpin, S., Brewster, D., Robinson, G., Guthridge, S. (2005). Skin infection, housing and social circumstances in children living in remote

- indigenous communities: testing conceptual and methodological approaches. *BMC Public Health*, 5; 128-139.
- Bdour, A., Altrabsheh, B., Hadadin, N., Al-Shareif, M. (2006). Assessment of medical wastes management practice: a case study of the northern part of Jordan. *Waste Management*, 27(6); 746–759.
- Belcher, D.W., Afoakwa, S.N., Osei-tutu, E., Wurapa, F.K., Osei, L. (1977). Endemic pyoderma in Ghana: a survey in rural villages. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 71; 204-209.
- Berger, D., Kirchner, G.O., Labenz, J. (2000). Needle stick injuries and hepatitis risk among healthcare workers. *Gastroenterology*, 118(4). Abstract n° 3904.
- Beyersmann, D. (2002). Effects of carcinogenic metals on gene expression. *Toxicology Letters*, 127(1-3); 63 – 68.
- Blenkharn, J.I., Odd, C. (2008). Sharps injuries in healthcare waste handlers. *Ann Occup Hyg*, 52; 281 – 286.
- Bo, D., Zhang, F-S., Zhao, L. (2009). Influence of supercritical water treatment on heavy metals in medical waste incinerator fly ash. *Journal of Hazardous Materials*, 170; 66-71.
- Brewer, G.J. (2010). Risks of copper and iron toxicity during aging in humans. *Chem. Res. Toxicol*, 23; 319–326.
- Carlton, C., Critto, A., Marcomini, A., Nathanail, P. (2001). Risk based characterization of contaminated industrial site using multivariate and geostatistical tools. *Environmental Pollution*, 111, 417-427.
- Chang, F-Y., Wey, M-Y. (2006). Comparison of the characteristics of bottom and fly ashes generated from various incineration processes. *Journal of Hazardous Materials*, B138; 594–603.
- Chang, Y-S., Kong, S-B., Ikonou, M.G. (1999). PCBs contributions to the total TEQ released from Korean municipal and industrial waste incinerators. *Chemosphere*, 39(15); 2629-2640.
- Charnley, G., Doull, J. (2005). Human exposure to dioxins from food, 1999 – 2002. *Food and Chemical Toxicology*, 43(5); 671 – 679.
- Chen, T., Yan, J.H., Lu, S.Y., Li, X.D., Gu, Y.L., Dai, H.F., Ni, M.J., Cen, K.F. (2008). Characteristic of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in fly ash from incinerators in China. *Journal of Hazardous Materials*, 150; 510-514.
- Coker, A., Sangodoyin, A., Sridhar, M., Booth, C., Olomolaiye, P., Hammond, F. (2009). Medical waste management in Ibadan, Nigeria: Obstacles and prospects. *Waste management*, Vol. 29(2), pp 804-811.
- Cole, E. (1998) Chemical and biological exposures and safety hazards in medical waste treatment facilities: an assessment of alternative technologies. International Healthcare Waste Network (IhcWaN). Vol. 98/2, No. 9; Cedex, France.
- Coutinho, M., Pereira, M., Rodrigues, R., Borrego, C. (2006). Impact of medical waste incineration in the atmospheric PCDD/F levels of Porto, Portugal. *Science of the Total Environment*, 362; 157-165.
- Crabb, C. (2003). Researchers argue that unsafe injections spread HIV more than unsafe sex. *Bull World Health Organ*, 81(4); 307.
- Curtale, F., Pezotti, P., Saad, Y.S., Aloï, A. (1999). An analysis of individual, household and environmental risk factors for intestinal helminth infection among children in Qena Governorate, Upper Egypt. *Journal of Tropical Pediatrics*, 44; 14-17.
- Dempsey, C.R., Oppelt, E.T. (1993). Incineration of hazardous waste: a critical review update. *Jnl. of Air and Waste Management Association*, 43; 23-73.

- Diaz, L.F., Savage, G.M., Eggerth, L.L. (2005). Alternatives for the treatment and disposal of healthcare wastes in developing countries. *Waste Management*, 25; 626-637.
- Erdem, Y.I., Talas, M.S. (2006). Blunt and penetrating object injuries in housekeepers working in a Turkish university hospital. *Am J Infect Control*, 34; 208 – 214.
- Fehr, R., Mekel, O., Welteke, R. (2004). HIA: the German perspective. In: Health Impact Assessment. (Ed. Kemm, J., Parry, J., Palmer, S.). Oxford University Press, 253-254.
- Figueroa, I.J., Hawranek, T., Abraha, A., Hay, J.R. (1997). Prevalence of skin diseases in school children in rural and urban communities in the Illubabor province, south-western Ethiopia: a preliminary survey. *Journal of the European Academy of Dermatology and Venereology*, 9; 142-148.
- Filipponi, P., Poletini, A., Pomi, R., Sirini, P. (2003). Physical and mechanical properties of cement-based products containing incineration bottom ash. *Waste Management*, 23, 145-156.
- Fogwe, Z.N., Ndifor, F.C. (2010). Tropical city mileux and disease infection: the case of Douala, Cameroon. *J Hum Ecol*, 30(2):123-130.
- Fongwa, M.N. (2002). International Health Care Perspectives: the Cameroon Example. *Journal of Transcultural Nursing* Vol. 13 (4); 325-330.
- Franka, E., El-Zoka, A.H., Hussein, A.H., Elbakosh, M.M., Arafa, A.K., Ghenghesh, K.S. (2009). Hepatitis B virus and hepatitis C virus in medical waste handlers in Tripoli, Libya. *Journal of Hospital Infection*, 72; 258 – 261.
- Garzon, M. (2003). Parasites- a holistic approach. In: Associates NIH, ed. Capital University of Integrated Medicine.
- Gidarakos, E., Petrantonaki, M., Anastasiadou, K., Schramm, K-W. (2009). Characterization and hazard evaluation of bottom ash produced from incinerated hospital waste. *Journal of Hazardous Materials*, 172; 935-942.
- Giroletti, E., Lodola, L. (1993). Medical waste treatment. ISPRA Courses: Waste treatment and management. <http://www-3.unipv.it/webgiro/ricerch/Public/ISPRA93-medicalWaste.pdf> (Accessed: 11 November 2010).
- Girón, S.L., Mateus, J.C., Méndez, F. (2009). Impact of an open waste disposal site on the occurrence of respiratory symptoms and on health care costs of children. *Biomédica*, 29; 392-402.
- Grassman, J.A., Mansten, S.A., Walker, N.J., et al. (1998). Animal models of human response to dioxins. *Environ Health Perspect*, 106(suppl 2), 761–75.
- Grochowalski, A. (1998). PCDDs and PCDFs concentration in combustion gases and bottom ash from incineration of hospital wastes in Poland. *Chemosphere*, 37(9-12); 2279-2291.
- Harris-Roxas, B., Harris, E. (2010). Differing forms, differing purposes: a typology of health impact assessment. *Environmental Impact Assessment Review*, doi:10.1016/j.eiar.2010.03.003
- Hassan, M.M., Ahmed, S.A., Rahman, K.A., Biswas, T.K. (2008). Pattern of medical waste management: existing scenario in Dhaka City, Bangladesh'' *BMC Public Health*, 8:36. Doi: 10.1186/1471-2458-8-36.
- Hasselriis, F. (1998). An assessment of realistic emission from municipal, medical, and hazardous waste incinerators. *Environmental Engineering Science*, 15(2); 171-181.
- Hagenmaier, H., Kraft, M., Brunner, H., Haag, R. (1987). Catalytic effects of fly ash from waste incineration facilities on the formation and decomposition of PCDDs and PCDFs. *Env. Sci. Tech.*, 21, 1080-1084.
- Hay, A. (1976). Toxic cloud over Seveso. *Nature*, 263; 636 – 638.
- Health Care Waste Summit (HCWS) 2008. <http://www.allconferences.com/conferences/20090806143133/> (Accessed on: 01-10-2008).

- Health Care Without Harm Europe (HCWH Europe, 2004). Non-incineration medical waste treatment technologies in Europe: a resource for hospital administrators, facility managers, health care professionals, environmental advocates, and community members. Prague, Czech Republic.
- Health Care Without Harm Europe (HCWH, 2001). Non-incineration medical waste treatment technologies in Europe: a resource for hospital administrators, facility managers, health care professionals, environmental advocates, and community members. Washington, DC.
- Heller, L., Catapreta, C.A.A. (2003). Solid waste disposal in urban areas and health – the case of Belo Horizonte, Brazil. *Waste Manage Res*, 21; 549-556.
- Hincrichs, R.A. (1992). Energy. Saunders College Publishing. United States of America.
- Hsieh, J., Confuorto, N. (1991). Operation of a medical waste incinerator and the emission control system. *SPIE*, 1717; 46 – 55.
- Huang, H., Bueckens, A. (1996). De novo synthesis of polychlorinated dibenzo-p-dioxins and dibenzofurans – proposal of a mechanistic scheme, *The Science of the Total Environment*, 93, 121-141.
- Hutzinger, O., Choudhry, G.G., Chittim, B.G., Johnston, L.E. (1985). Formation of polychlorinated dibenzofurans and dioxins during combustion, electrical equipment fires and PCB incineration. *Environmental Health Perspectives*, 60; 3 – 9.
- Hyland, R.G. (1993). Regulatory developments affecting medical waste disposal. (In. 86th Annual Meeting and Exhibition) Air and Waste Manage Assoc., Paper No. 93-TA-47.03, Denver, CO.
- Institute for Prospective Technological Studies (IPTS) (1999). The incineration of waste in Europe: issues and perspectives. A report for the committee for environment, public health and consumer protection of the European Parliament, (*EUR 18717 EN*), ECSC-EEC-EAEC Brussels, Belgium.
- International Agency for Research on Cancer (IARC, 1997). Carcinogenic Risk Associated with Dioxins. Press release, February 14, 1997. Lyon, France.
- International Agency for Research on Cancer (IARC, 1987). Overall evaluations of carcinogenicity: an updating of IARC monographs. Lyon, France.
- Jahan, S (2005). Epidemiology of needle stick injuries among health care workers in a secondary care hospital in Saudi Arabia. *Ann Saudi Med*, 25(3); 233-238.
- Jang, Y.C., Lee, C., Yoon, O.S., Kim, H. (2006). Medical waste management in Korea. *Journal of Environmental Management*, 80, 107–115.
- Jin, J., Li, X., Chi, Y., Yan, J. (2010). Heavy metal stabilization in medical waste incinerator fly ash using alkaline assisted supercritical water technology. *Waste Management and Research*, 0(0); 1-10.
- Joffe, M., Mindell, J. (2002). A framework for the evidence base to support health impact assessment. *J Epidemiol Community Health*, 56; 132-138.
- Kerdsuwan, S. (2000). Case study of using hospital waste incinerator in Thailand. In: 93rd Annual meeting and Exhibition, Air and Waste Manage. Assoc. paper No. 00-107, Salt lake City, UT, 18-22 June.
- Ketlogetswe, C., Oladiran, M.T., Foster, J. (2004) Improved combustion processes in medical wastes incinerators for rural applications. *African Journal of Science and Technology*, 5(1); 67-72.
- Kezaala, R. (2002). Injection waste management in immunization campaigns: lessons and orientations for 2002. Unpublished WHO document presented at The Annual Meeting of EPI Managers, West Africa Block, Lomé, Togo. 20-23 March, 2002. World Health Organization Regional Office for Africa, Harare, Zimbabwe.

- Kjellstrom, T., van Kerkhoff, L., Bammer, G., McMichael, T. (2003). Comparative assessment of transport risks - how it can contribute to health impact assessment of transport policies. *Bulletin of the World Health Organization*, 81(6); 451-547.
- Klicius, R., Finkelstein, A. (1988). The national incinerator testing and evaluation program: environmental characterization of mass burning incinerator technology at Quebec City. Environment Canada Report, EPS 3/UP/5. Environment Canada, Ottawa, Ontario, Canada.
- Kuo, H-W., Shu, S-L., Wu, C-C., Lai, J-S. (1999). Characteristics of medical waste in Taiwan. *Water, Air and Soil Pollution*, 114; 413 – 421.
- Krisiunas, E. (2001). Emerging technologies for the treatment of medical waste: considerations for the Commonwealth of Dominica. WNNW International, Inc. Burlington, Connecticut (06013) USA.
- Labib, O.A., Hussein, A.H., El-Shall, W.I., Zakaria, A., Mohamed, M.G. (2005). Evaluation of medical waste incinerators in Alexandria. *The Journal of the Egyptian Public Health Association*, 80(3&4); 389 – 404.
- Labunska, I., Brigden, K., Johnston, P., Santillo, D., Stringer, R. (2000). Concentrations of heavy metals and organic contaminants in ash collected from the Izmit hazardous/clinical waste incinerator. Greenpeace Research Laboratories, Technical Note 02/2001.
- Lee, C.C., et al. (1988). A review of biomedical waste disposal: incineration fact sheet. Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.
- Lee, C.C. and Huffman, G.L. (1993). Metals behavior during medical waste incineration. ACS Symposium series, 515; 189 – 198.
- Lee, W-J., Liow, M-C., Tsai, P-J., Hsieh, L-T. (2002). Emission of polycyclic aromatic hydrocarbons from medical waste incinerators. *Atmospheric Environment*, 36(5); 781 – 790.
- Lee, W-S., Chang-Chien, G-P., Wang, L.C., Lee, W-J., Tsai, P-J., Chen, C-K. (2003). Emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans from the incineration of both medical and municipal solid wastes. *Aerosol and Air Quality Research*, 3(1); 01-06.
- Liem, A.K., Furst, P., Rappe, C. (2000). Exposure of populations to dioxins and related compounds. *Food Addit Contam*, 17(4); 241 – 259.
- Luttrell, W.E., Bisesi, M.S., Bisesi, C.A. (2003). Hazardous waste management. (In. The Occupational environment: its evaluation, control and management. (2nd Ed.) AIHA Publications, Fairfax, VA.
- MacIntyre, S. and Petticrew, M. (2000). Good intentions and received wisdom are not enough. *J Epidemiol Community Health*, 54; 802-3.
- Magee, R.S. (1989). Plastics in municipal solid waste incineration- a literature study. Prepared by the New Jersey Institute of Technology Hazardous Substance Management Center for the Society of Plastics Industry, Inc., January, 1989.
- Maliszewska-Kordybach, B. (1999). Sources, concentration, fate and effects of polycyclic aromatic hydrocarbons (PAHs) in the environment. Part A: PAHs in Air. *Polish Journal of Environmental Studies*, 8(3); 131-136.
- Manyele, S.V. and Lyasenga, T.J. (2010). Factors affecting medical waste management in low level health facilities in Tanzania. *African Journal of Environmental Science and Technology*, 4(5); 304-318.
- Marinkovic, N., Vitale, K., Holcer, N.J., Dzakula, A., Pavic, T. (2008). Management of hazardous medical waste in Croatia. *Waste management*, 28; 1049-1056.
- Mastral, A.M., Callen, M.S., Murillo, R., Garcia, T. (1999). Organic atmospheric pollutants: polycyclic hydrocarbons from coal atmospheric fluidized bed combustion (AFBC). *Global Nest: The International Journal*, 1; 111–119.

- Mehraj, V., Hatcher, J., Akhtar, S., Rafique, G., Beg, M.A. (2010). Prevalence and factors associated with intestinal parasitic infection among children in an urban slum of Karachi. *PLoS ONE*, 3(11). e3680. doi:10.1371/journal.pone.0003680.
- Mbongwe, B., Mmereki, B.T., Magashula, A. (2008). Healthcare waste management: current practices in selected healthcare facilities, Botswana. *Waste Management*, 28; 226–233.
- McCormack, J. et al. (1989). Evaluation test on a small hospital refuse incinerator at saint Bernardine's hospital in San Bernardino, California. *California Air Resources Board*.
- McRae, G. (1997) Medical waste strategies treatment and technologies: a basic overview for developing countries. (In. SPREP Waigani Convention Handbook). The Reference Library.
- McVeigh, P. (1993). OR nursing and environmental ethics. Medical waste reduction, reuse, and recycling. *Today's OR nurse*, 15(1), 13-18.
- Mohee, R. (2005). Medical Wastes Characterization in Healthcare Institutions in Mauritius. *Elsevier*.
- Moritz, J.M. (1995). Current legislation governing clinical waste disposal. *Journal of Hospital Infection*, 30 (supplement), 521-530.
- Mumtaz, S., Siddiqui, H., Ashfaq, T. (2009). Frequency and risk factors for intestinal parasitic infections in children under five years of age at tertiary care hospital in Karachi. *Journal of Pakistani Medical Association*, 59(4); 216-219.
- National Research Council (NRC, 2000) of the National Academies. Waste incineration and public health. Washington, DC.
- National Research Council (NRC, 2006) of the National Academies. Managing coal combustion residues in mines. Committee on Mine Placement of Coal Combustion Wastes, Washington, DC.
- National Academy of Science (2000). Waste incineration and public health. Free Executive Summary, www.nap.edu/permissions/.
- National Institute of Statistics (NIS, 2005). <http://www.statistics-cameroon.org/>
- Neulicht, R. (1987). Results of the combustion and emissions research project at the Vicon Incinerator Facility in Pittsfield, Massachusetts. Final Report, Volume I, prepared by Midwest Research Institute for New York State Energy Research and Development Authority, Report 87-16, June, 1987.
- New Jersey State Department of Environmental Protection (N.J. SDEP, 1989). Report of emission tests. Helene Fuld Medical Center, Trenton, New Jersey. December 1, 1989.
- Niessen, R.W. (2002). Combustion and incineration processes. Third edition, Marcel Dekker, Inc. 270 Madison Ave, New York.
- Northwest Regional Delegation of Public Health (NWRDPH, 2005). Annual Report.
- Office of Technology Assessment (OTA, 1988), U.S. Congress. Issues in medical waste management - background paper. Washington, DC; U.S. Government Printing Office, October 1988 (OTA-BP-O-49).
- Office of Technology Assessment (OTA, 1990). Finding the Rx for managing medical wastes. US Congress, OTA-O-459. Government Printing office, Washington, DC.
- Oke, I.A. (2008). Management of immunization solid wastes in Kana State, Nigeria. *Waste Management*, 12(25); 12-21.
- Ozonoff, D., Colten, M.E., Cupples, A., Heeren, T., Schatzkin, A., Mangione, T., Dresner, M., Colton, T. (1987). Health problems reported by residents of a neighborhood contaminated by a hazardous waste facility. *American Journal of Industrial Medicine*, 11(5); 581-597.
- Parry, J. and Stevens, A. (2001). Prospective health impact assessment: pitfalls, problems and possible ways forward. *BMJ*, 323; 1177 – 1182.

- Patil, A.D., Shekdar, A.V. (2001). Health-care waste management in India. *Journal of Environmental Management*, 63; 211-220.
- Petticrew, M., Macintyre, S., Thomson, H. (2004). Evidence and HIA. In: Health Impact Assessment. (Ed. Kemm, J., Parry, J., Palmer, S.). Oxford University Press, 75-79.
- Phillips, G. (1999). Microbiological aspects of clinical waste. *Journal of Hospital Infection*, 41:1-6.
- Phengxay, S., Okumura, J., Miyoshi, M., Sakisaka, K., Kuroiwa, C and Phengxay, M. (2005). Health-care waste management in Lao PDR: a case study. *Waste Management Research*, 23; 571-581.
- Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.
- Pruss, A., Giroult, E., Rushbrook, P. (1999). Safe management of wastes from health-care activities. World Health Organization, Geneva.
- Pruss-Ustun, A., Rapiti, E., Hutin, Y. (2005). Estimation of the global burden of disease attributable to contaminated sharps injuries among health-care workers. *American Journal of Industrial Medicine*, 48; 482-490.
- PRISM Bangladesh (2002). Survey report on hospital waste management in Dhaka city.
- Qdais, H.A., Rabi, A., Abdulla, F. (2007). Characteristics of medical waste generated at the Jordanian hospitals. *Clean Techn Environ Policy*, 9; 147 – 152.
- Quigley, R., den Broeder, L., Furu, P., Bond, A., Cave, B., Bos, R. (2006). Health Impact Assessment: international best practice principles. Special publication series No. 5, Fargo, USA: International Association for Impact Assessment.
<http://iaia.org/publicdocuments/special-publications/SP5.pdf>. Accessed April 15, 2011.
- Quigley, R., Taylor, L. (2004). Evaluating health impact assessment. *Journal of Public Health*, 118; 544-52.
- Racho, P., Jindal, R. (2004). Heavy metals in bottom ash from a medical waste incinerator in Thailand. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 8(1); 31-38.
- Ratner, P., Green, L.W., Frankish, C., Chomick, T., Larsen, C. (1997). Setting the Stage for Health Impact Assessment. *Journal of Public Health Policy*, 18(1); 67-79.
- Reinhardt P.A., Gordon, J.G. (1991). Infectious and medical waste management. Lewis Publishers Inc., Michigan, USA.
- Research Triangle Institute (1989). Medical waste treatment techniques. Draft final report, prepared for (under subcontract to Dynamic Corp., Rockville, MD) EPA Contract No. 68-01-7266. Research Triangle Park.
- Reuters News Agency (2008). Afghanistan: medical waste poses health risks in urban areas, 14/10/2008.
www.alertnet.org/thenews/newsdesk/IRIN/fb0b02c252900fd18716034303f6dcc4.htm. Accessed 13/04/2011.
- Rigo, H.G., Chandler, A.J. (1995). The relationship between chlorine in the waste stream and dioxin emissions from combustor stacks. ASME Research Report, CRTD, Vol. 36.
- Rogers, D.E.C., Brent, A.C. (2006). Small-scale medical waste incinerators – experiences and trials in South Africa. *Waste Management*, 26(11); 1229-1236.
- Rushton, L. (2003). Health hazards and waste management. *British Medical Bulletin*, 68; 183-197.
- Rutala, W.A., Mayhall, C.G. (1992). Medical waste. Position paper, The Society for Hospital Epidemiology of America. *Infect Control and Hosp Epidemiol*. 13:38-48.

- Rutala, W., Sarubbi, F. (1983). Management of Infectious Waste from Hospitals. *Infectious Waste Management*, 4(4); 198-203.
- Sagoe-Moses, C., Pearson, R.D., Perry, J., Jagger, J. (2001). Risks to health care workers in developing countries. *N Engl J Med*, 345(7); 538 – 540.
- Sarkar, S.K.L., Haque, M.Z., Khan, T.A. (2006). Hospital waste management in Sylhet City, Bangladesh. *ARPJ Journal of Engineering and Applied Sciences*, 1(2); 1-9.
- Sawalem, M., Selic, E., Herbell, J.-D. (2008). Hospital waste management in Libya: A case study. *Waste Management*, Vol. 29, pp 1370–1375.
- Sawell, S.E., Bridle, T.R., Constable, T.W. (1988). Heavy metal leachability from solid waste incinerator ashes. *Waste Management Research*, 6; 227-238.
- Sbrilli, A., Mininni, G., Guerriero, E., Rotatori, M., Molinelli, M.L., Lotito, V. (2003). PCDD/Fs emissions from hospital waste incineration. Proceedings of the European Combustion Meeting.
- Shane, B.S., Henry, C.B., Hotchkiss, J.H., Klausner, K.A. (1990). Organic toxicants and mutagens in ashes from eighteen municipal refuse incinerators. *Arch. Environ: Contam. Toxicol*, 19; 665-673.
- Sharma, S. (2010). Awareness about Bio-medical waste management among health care personnel of some important medical centers in Agra. *International Journal of Environmental Science and Development*, 1(3); 251-255.
- Shen, C., Tang, X., Yao, J., Shi, D., Fang, J., Khan, M.I., Cheema, A.S., Chen, Y. (2010). Levels and patterns of polycyclic aromatic hydrocarbons and polychlorinated biphenyls in municipal waste incinerator bottom ash in Zhejiang province, China. *Journal of Hazardous Materials*, 179; 197-202.
- Shiao, J., Guo, L., McLaws, M.-L. (2002). Estimation of the risk of blood borne pathogens to health care workers after a needle stick injury in Taiwan. *Association for Professionals in Infection Control and Epidemiology, Inc.*, 30(1); 15-30.
- Simard, E.P., Miller, J.T., George, P.A., Wasley, A., Alter, M.J., Bell, B.P., Finelli, L. (2007). Hepatitis B vaccination coverage levels among healthcare workers in the United States, 2002-2003. *Infect Control Hosp Epidemiol*, 28(7):783-90.
- Singh, S., Prakash V. (2007). Toxic environmental releases from medical waste incineration: a review *Environ Monit Assess*, Vol. 132, pp 67-31.
- Slavik, N. (1987). Report on the Proceedings of the EPA Infectious Waste Management Meeting. Washington, DC.
- Solberg, K.E. (2009). Trade in medical waste causes deaths in India. *Lancet*, 373; 1067.
- Spurgin, R. and Spurgin Assoc. (1990). Medical waste treatment technologies. Contract report for the Office of Technology Assessment (U.S. Congress), Washington, DC.
- Steketee, R.W. (2003). Pregnancy, nutrition and parasitic diseases. *J Nutri*, 133; 1661S-1667S.
- Stieglitz, L., Zwick, G., Beck, J., Bautz, H., Roth, W. (1989). Carbonaceous particles in fly ash – A source for the de novo synthesis of organochloro compounds. *Chemosphere*, 19; 283–290.
- Sukandar, S., Yasuda, K., Tanaka, M., Aoyama, I. (2006). Metals leachability from medical waste incinerator fly ash: a case study on particle size composition. *Environmental Pollution*, 144; 726-735.
- Summers, J. (1991). Asset disposal: follow company policies or follow the law? *J. Healthc. Mater Manage*, 9(4), 54-56.
- Taghipour, H. and Mosafieri, M. (2009). Characterization of medical waste from hospitals Tebriz, Iran. *Science of the Total Environment*, 407; 1527-1535.

- Talaat, M., Kandeel, A., El-Shoubary, W., Bodenschatz, C., Khairy, I., Oun, S., Mahoney, F.J. (2003). Occupational exposure to needle sticks injuries and hepatitis B vaccination coverage among health care workers in Egypt. *Am J Infect Control*, 31(8):469-74.
- Tan, Z., Xiao, G. (2010). Leaching characteristics of fly ash from Chinese medical waste incineration. *Waste Management and Research*, 0(0); 1-10.
- Thacker, N., Kashyap, S., Trivedi J.T., Thokchom, B., Agnihotri, A. (*unpublished*). Dioxin and furan in waste incinerations and thermal processes. National Environmental Engineering Research Institute, Nehru Marg, Nagpur-440020, India.
- The International Health Care Waste Summit (IHCWS, 2008). Available at: <http://www.allconferences.com/conferences/20080806143133/> (Accessed on 07/10/2008).
- The Postnewsline (2005). Up Station Mountain Club: HYSACAM and disposal of hospital waste, 11 June 2005. http://www.postnewsline.com/2005/06/stronghysacam_a.html (Accessed on 12/04/2011).
- Tsakona, M., Anagnostopoulou, E., Gidarakos, E. (2007). Hospital waste management and toxicity evaluation: a case study. *Waste Management*, 27: 921-920.
- U.S. Environmental Protection Agency. (U.S. EPA, 1986). Guide for infectious waste Management, EPA/530-SW-86-014. Washington, DC.
- U. S. Environmental Protection Agency (U.S. EPA, 1988). Hospital waste combustion study: data gathering phase. EPA-450/3-88-017, Research Triangle Park, North Carolina.
- U. S. Environmental Protection Agency (U.S. EPA, 1994). Estimating exposure to dioxin-like compounds, volume I: Executive Summary, Office of Research and Development, EPA/600/6-88/005Ca. Jun 1994 review draft, p. 36.
- U.S. Environmental Protection Agency. (U.S. EPA, 2001). Database of sources of environmental releases of dioxin like compounds in the United States. EPA/600/C-01/012.
- U.S. Environmental Protection Agency. (U.S. EPA, 2000). Exposure and health assessment for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and related compounds: PART III Integrated summary and risk characterization for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and related compounds. Available: <http://www.epa.gov/ncea/pdfs/dioxin/dioxreass.htm>. [Accessed 23 November 2010].
- U.S. Environmental Protection Agency. (U.S. EPA, 2003). Framework for cumulative risk assessment, External review draft, EPA/630/P-02/001A, Risk assessment forum, U.S. Environmental Protection Agency, Washington, DC 20460. April 23.
- U.S. Environmental Protection Agency (U.S. EPA, 2007). Human and ecological risk assessment of coal combustion wastes. Research Triangle Park (RTI), Washington, DC.
- United Nations Conference on Environment and Development (UNCED). Proceedings of the United Nations Conference on Environment and Development, Rio de Janeiro, Brazil: Agenda 21. <http://www.un.org/geninfo/bp/enviro.html>
- Vadic, V., Hrsak, J., Kalinic, N., Cackovic, M., Sega, K. (2000). Seasonal differences in the levels of gaseous air pollutants in the vicinity of a waste dump. *Environmental Monitoring and Assessment*, 65; 147 – 153.
- Valavanidis, A., Iliopoulos, N., Fiotakis, K. (2008). Metal leachability, heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls in fly ash and bottom ashes of a medical waste incineration facility. *Waste Management & Research*, 26; 247-255.
- Van den Berg, M., Birnbaum, L., Bosveld, A.T.C., Brunstrom, B., Cook, P., Feeley, M. et al. (1998). Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. *Environmental Health Perspective*, 106; 775-792.
- Vehlow, J., Bergfeldt, B., Hunsinger, H. (2006). PCDD/F and related compounds in solid residues from municipal solid waste incineration: a literature review. *Waste Manage Res*, 24; 404-420.

- Vrijheid, M. (2000). Health effects of residence near hazardous waste landfill sites: a review of epidemiological literature. *Environ Health Perspect*, 108; 101-112.
- Wang, D-G., Yang, M., Jia, H-L., Zhou, L., Li, Y-F. (2008). Levels, distribution and profiles of polychlorinated biphenyls in surface soils in Dalian, China. *Chemosphere*, 73(1); 38-42.
- Wagner, J., Green, A. (1993). Correlation of chlorinated organic compound emissions from incineration with chlorinated organic input. *Chemosphere*, 26; 2039-2045.
- Wheatley, A.D., Sadhra, S. (2004). Polycyclic aromatic hydrocarbons in solid residues from waste incineration. *Chemosphere*, 55; 743-749.
- Williams, P.T. (1994). Pollutants from incineration: an overview. (In. Waste incineration and the environment) Hester R.E. and Harrison R.A. (Editors). The Royal Society of Chemistry, Cambridge.
- World Health Organization (WHO, 1985). Management of waste from hospitals and other health care establishments. Report on a WHO meeting. *EURO Rep Stud.*, 97; 1-61.
- World Health Organization (WHO, 1999). Safety of injections. WHO-UNICEF-UNFPA joint statement on the use of auto-disable syringes in immunization services. Geneva: WHO Department of Vaccines and Biologicals, 1999 (WHO/V&B/1999.25).
- World Health Organization (WHO, 2001). Review of health impacts from microbiological hazard in health-care wastes. WHO, Geneva, (Draft). http://www.who.int/docstore/water_sanitation_health/Environmental_sanit/Healthcarewaste/himpacts.pdf. Accessed 14/10/2010.
- World Health Organization (WHO, 2003). Aide memoire for a national strategy for safe and appropriate use of injections. Department of blood and safety and clinical technology, Geneva, Switzerland.
- World Health Organization (WHO, 2005). The global patient safety challenge 2005.2006: clean care is safer than care. Geneva, Switzerland. www.who.int/gpsc/resources/en/. Accessed 11/10/2010.
- World Health Organization (WHO, 2005a). Healthcare waste management (HCWM): healthcare waste and its safe management. http://www.healthcarewaste.org/en/115_overview.html. Accessed, April 14, 2011.
- World Health Organization (WHO, 2007). Wastes from healthcare activities. WHO fact sheet No. 253, reviewed November 2007. <http://www.who.int/mediacentre/factsheets/fs253/en/>. Accessed 14/04/2011.
- World Health Organization (WHO) and the World Bank (WHO and World Bank, 2005). Better healthcare waste management: an integral component of health investment. WHO Library Cataloguing in Publication Data. ISBN 92-9021-389-2.
- Yan, J.H., Peng, Z., Lu, S.Y., Li, X.D., Ni, M.J., Cen, K.F., Dai, H.F. (2007). Degradation of PCDD/Fs by mechanochemical treatment of fly ash from medical waste incineration. *Journal of Hazardous Materials*, 147; 652-657.
- Zhao, L., Zhang, F-S., Chen, M., Liu, Z., Wu, D.B.J. (2010). Typical pollutants in bottom ashes from a typical medical waste incinerator. *Journal of Hazardous Waste*, 173; 181-185.
- Zhao, L., Zhang, F-S., Hao, Z., Wang, H. (2008). Levels of polycyclic aromatic hydrocarbons in different types of hospital waste incinerator ashes. *Science of the Total Environment*, 397; 24-30.